G.C.H.Q.
LIBRARY

C

JOURNAL OF SCIENTIFIC INSTRUMENTS

VOL. 32 NO. 1 JANUARY 1955

CONTENTS

ORIGINAL CONTRIBUTIONS

PAGE

Papers

A recording volumeter for small gas evolutions — By W. E. Hoare — 1
An apparatus for the measurement of dynamic mechanical properties of polymers over a wide temperature range — By D. W. Robinson — 2
An optical interferometer method of calibrating a crystal gauge for the measurement of sound wave transients — By G. J. Barber — 7
A machine for the measurement of rolling friction — By J. Halling — 8
Infra-red filters using evaporated layers of lead sulphide, lead selenide and lead telluride — By J. G. N. Braithwaite — 10
The production of accurate linear scales by means of the Merton nut — By L. A. Sayce — 11
The processing and some characteristics of coaxial cylinder, corona stabilizer tubes — By A. J. L. Collinson and D. W. Hill — 13
A measuring apparatus employing a reference line of variable brightness — By C. S. Lees — 17
A combined strain and curvature gauge for use in testing concrete beams — By J. M. Prentis — 19
An apparatus giving an α-particle microbeam for the irradiation of living cells — By H. A. B. Simons — 21
On the preparation of precision resolving-power test objects — By G. D. Dew — 24
Analysis of ortho- and para-hydrogen mixtures by the thermal conductivity method — By A. T. Stewart and G. L. Squires — 26
The necessary torque requirements for a servo-motor — By J. C. West and J. L. Leonard — 30

Laboratory and workshop notes

An adjustable bilateral slit for use with a photomultiplier in a soft X-ray spectrometer — By P. Fisher — 32
An automatic thermostat warming-up device — By M. W. Jervis — 33
An effective method of gripping short specimens of wire strand for tensile tests — By F. D. Hills — 33
A method of estimating distortion in cloud chamber tracks — By N. Cusack and P. Stott — 34
The preparation of unbacked gold films of known thickness — By W. E. Spear — 34
A multi-range laboratory flowmeter — By K. H. Todhunter and B. Wolstenholme — 35

NOTES AND NEWS

Correspondence

A trap-current controlled emission regulator for a mass spectrometer ion-source — From D. Greenhalgh and P. M. Jeffery — 36
Photographic enlargement and reduction in one dimension only — From R. N. Bracewell — 37

New instruments, materials and tools — 38
Electronic motor controller — Pipette control — Germanium junction photocells and power rectifiers
Pulse height analyser — Stylus oscillograph — Precision potentiometers — Precision vernier potentiometer

Notes and comments — 40

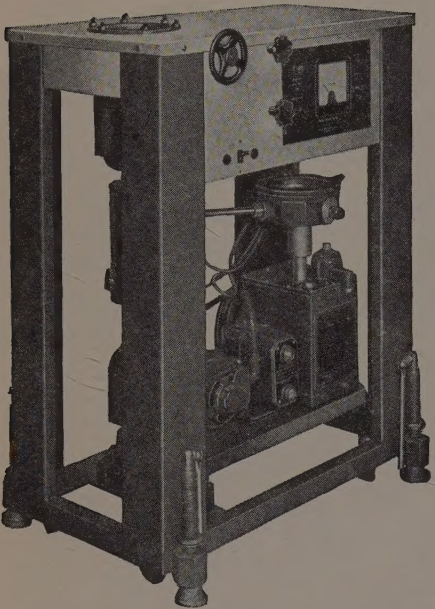
INDEX TO ADVERTISERS — xxviii

THE INSTITUTE OF PHYSICS, 47 BELGRAVE SQUARE, LONDON, S.W.1

Price 8s. (annual subscription £4)

Precision **VACUUM LEAK TESTIN**

applied ***INDUSTRIALLY!***

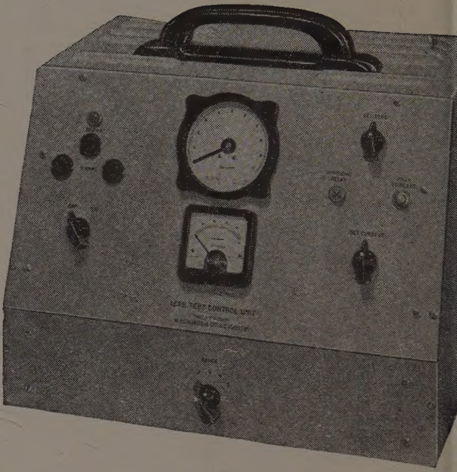


Manufacturers requiring to locate leaks of the order of 10^{-4} lusecs can achieve this high standard of sensitivity easily . . . speedily and economically with an EDWARDS standard Palladium-Barrier Leak Detector. Utilising a simple tracer-gas technique this instrument possesses a response approaching that of the mass-spectrometer—*but without its complications.*

★ **Best results are achieved, as with all detection systems, when used with a pumping system specially designed for leak detection.**

Standard leak-test pumping systems are designed by W. Edwards.

SEND FOR COMPLETE DETAILS



W. EDWARDS
& CO. (LONDON) LTD
MANOR ROYAL · CRAWLEY · SUSSEX
CRAWLEY 1500 (10 lines) EDCOHIVAC CRAWLEY

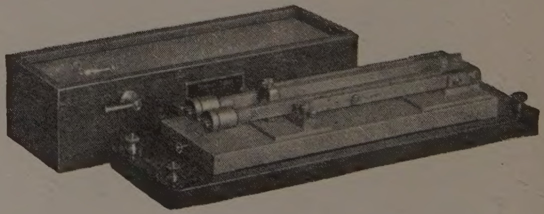
for better vacuum service

BRANCHES: GLASGOW & TORONTO. AGENTS THROUGHOUT THE WORLD

TINSLEY

PRECISION MEASURING INSTRUMENTS

The electrically maintained tuning-fork is a simple and accurate means of providing a standard frequency for timing purposes. It is used extensively in connection with chronoscopes for measuring small time intervals, and also in the accurate measurements of the speed of machines stroboscopically. This latter method has been adopted as the standard practice for the calibration of engine speed indicators. The fork normally carries two contacts, one is used for maintaining the fork and the other is available for driving a chronoscope, phonic motor, or flashing a stroboscopic lamp.



50 c/s Tuning-fork—Type 3086

For further information on tuning-forks and stroboscopic apparatus, write for list No. 69.

H. TINSLEY & Co., Ltd., Werndee Hall, London, S.E.25
and at St. Jerome, P.O. Canada

TELEPHONE: ADDiscombe 1400 & 3680

TELEGRAMS: Addiscombe 1400

ORIGINAL CONTRIBUTIONS

A recording volumeter for small gas evolutions

By W. E. Hoare, D.Sc.(Eng.), F.I.M., Tin Research Institute, Greenford, Middlesex

[*Paper first received* 31 *May, and in final form* 21 *June*, 1954]

A device is described for recording the movement of a mercury index in a volumeter tube. The instrument can record gas evolution rates up to 2 ml. per min and has an instrument sensitivity of 0·012 ml.

tudying the corrosion behaviour of tinned steel (tinplate) ecame necessary to establish a rate-time curve for the ution of hydrogen from a small tinplate specimen during attack. The apparatus developed for this purpose may ibly be useful in other fields of research.

he dimensions of the problem may be summarized as ws:

aximum total amount of hydrogen evolved, approximately 3 ml;

ıration of experiment, 100–1000 s;

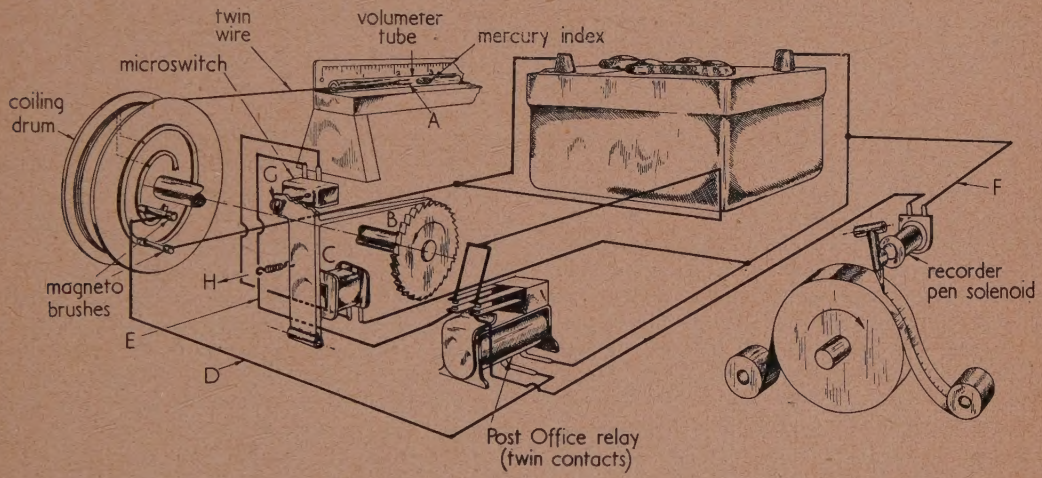
nge of rate in a single experiment, 0–2 ml. per min.

he apparatus comprises a thermostatically-controlled tion vessel connected, *via* a vapour trap, to a horizontal meter tube. From the viewpoint of instrument design, reaction vessel incorporates no especially novel features does not require description here. It may be mentioned, ever, that provision is made to connect the corroding imen and a suitable reference electrode to a high-speed rding potentiometer. This enables an electrode potential to be made concurrently with the gas-evolution record.

ie voltmeter itself is a 2·5 mm precision bore glass tube, n long, containing an index or thread of mercury about cm long. Smooth movement of the mercury index is red by baking a coating of silicone DC 703 on to the of the tube and by tilting the tube 2–3° downwards rds the open end. This slight tilt, controlled by elling" screws, does not significantly affect the pressure e reaction vessel.

olution of gas in the reaction vessel causes movement of ndex along the volumeter tube and the movement can, ourse, be recorded by observation. This is, however, tedious at low rates and can become almost impossible at higher rates. The simple tracker mechanism and recorder described below gives excellent records and has been in regular use for several months without trouble.

The construction and operation of the mechanism is shown very schematically in the diagram. The tracker wire, which follows the movement of the index, is a length of twin thermocouple wire (36 s.w.g. iron-eureka conductors, double-silk covered, laid flat together and double-silk covered overall) with bared platinum-pointed ends *A*. The other end of the wire is coiled on to a light perspex drum and connected through the body of the drum to copper contact rings engaging with magneto brushes. The coiling drum is driven anticlockwise by a ratchet *B* operated by an impulse relay *C*. A simple clutch, formed from two contrate wheels, enables the drum to be disconnected from the ratchet drive for rewinding.



Schematic diagram of volumeter and circuits

There are three straightforward electrical circuits all powered from a 12 V battery or other suitable source. The index circuit *D* comprises the tracker wire, the mercury index, the solenoid of a Post Office relay and the battery. When the index moves along the tube and touches the platinum points of the tracker wire this circuit is completed and both pairs of contacts on the Post Office relay armature close. The tracker circuit *E* comprises one pair of Post Office relay contacts, the solenoid of the impulse relay, a microswitch normally in the closed position, and the battery. Closing of the Post Office relay contacts causes the following actions. The impulse relay solenoid is energized and pulls in its armature with the driving pawl attached, the movement being so adjusted that the pawl clicks over one tooth of the ratchet wheel. The very last part of the movement of the armature is used to open the microswitch by means of the button *G*. The circuit is thus broken, the spring *H* causes the pawl to drive the ratchet wheel one tooth anti-clockwise, and the coiling drum pulls the tracker wire back from the mercury index. Both circuits are now open and await the next completion of the index circuit. The third circuit *F* is simply a solenoid-operated pen actuated by the second pair of Post Office relay contacts. Each movement of the index is recorded by a corresponding tick on a paper tape driven at constant speed.

In the present arrangement, the number of teeth on the ratchet wheel (104) and the diameter of the coiling drum (8·2 cm) are such that the unit of volume recorded is 0·012 ml, corresponding to 0·25 cm movement of the mercury index.

At the conclusion of an experiment the mercury index is drawn back to the zero position by applying suction at a T-piece at the right-hand end of the tube, and the trac wire is wound back into the tube by means of small rubb covered rollers at the left-hand end.

Previous devices based on a double escapement actua by two solenoids proved less satisfactory than the pres design.

ACKNOWLEDGEMENTS

The writer is indebted to the International Tin Resea Council for permission to publish this note and to his collea Mr. R. Mills, who contributed to the design of the devi The instrument was constructed by the workshop staff of Tin Research Institute.

An apparatus for the measurement of dynamic mechanical properties of polymers over a wide temperature range

By D. W. Robinson, B.Sc., D.Phil., Imperial Chemical Industries Ltd., Plastics Division, Welwyn Garden City, Herts.

[*Paper first received* 10 *August, and in final form* 11 *October*, 1954]

An apparatus for the measurement of the dynamic mechanical properties of polymers from 20 to 600° K is described. Transverse resonance vibrations are excited in a reed of the polymer which is clamped at one end, the vibration amplitude of the free end being detected photoelectrically and displayed on an oscilloscope. Higher overtone modes of vibration can be measured by suitable amplification of this signal and the dynamic Young's modulus and internal friction (mechanical losses) are deduced from the resonant frequency and width of the resonance curve. Temperature control is achieved by an adiabatic vacuum technique whereby the specimen is brought to the desired temperature through a controlled heat transfer from either a refrigerant (liquid nitrogen or liquid hydrogen) or hot silicone oil and then thermally isolated in a vacuum at this particular temperature.

In general, a molecular interpretation of the time and temperature dependent physical properties of high polymers can be approached by one of two methods. The first considers the material as an assembly of elastic and viscous elements, suitably combined and distributed according to a retardation or relaxation function which describes the contribution from all the elements to the observed viscoelastic response of the material. This mathematical function, derived from experimental results, has been used in attempts to relate physical properties and molecular structure.(1, 2) The second, a somewhat more phenomenological approach, utilizes the observed experimental results on a series of chemically related polymers and seeks to identify common features of their viscoelastic response with molecular features specifically introduced by chemical synthesis.(3, 4, 5)

In dealing with the correlation of mechanical properties with polymer structure, it is usual to employ three experimental methods: creep under constant load and stress relaxation at constant extension for low frequency investigations, and steady state response to sinusoidal stresses (dynamic experiments) for intermediate and high frequency studies. All three methods can be used to calculate approximate distribution functions although, as Schwarzl(6) has shown, the dynamic results lead to more accurate approximations. Moreover, Ferry and Fitzgerald(1) emphasize the fact that both in-phase and out-of-phase responses can be derived from a single dynamic experiment, whereas a transient experiment yields only a single function of time (the modulus). In principle, it should be possible with all three methods to detect small changes in the measured property arising from molecular rearrangements. In practice, however, only large changes such as the rubber–glass transitions are observed in relaxation and creep curves, whereas secondary structural features, t effects of which can be demonstrated by dynamic expe ments,(3, 4, 5) remain unresolved.

A diversity of dynamic methods is available ranging fr forced or free torsional vibrations in the few cycles per seco region(5, 7) to the pulse and stationary methods at megacy frequencies.(8) The intermediate audio-frequency range h been covered by a number of resonance methods(9–13) and torsional damping experiments.(14) Owing to numer experimental difficulties, it has not been possible to use a one apparatus over a wide temperature and frequency ran however, a recent international testing programme h demonstrated the feasibility of a complete study of t viscoelastic properties of high polymers using results obtain from various types of apparatus.(15)

A double transducer apparatus designed by Ferry a Fitzgerald(16) gives precise measurements in the aud frequency range between 223 and 423° K and this appe to be the first attempt at simultaneous frequency and te perature coverage over an appreciable range. The resu obtained(17) with this apparatus have demonstrated validity of Ferry's reduction scheme(18) over a temperat range for a number of polymers. This scheme interrela mechanical properties which are measured at differ frequencies and temperatures by means of a shift fact This frequency shift factor has also been shown to v inversely as the square of the absolute temperature moderately low temperatures. The existence of such regular relationship is an important fact, for assuming reduction scheme to apply to most materials it justifies some extent the development of dynamic experiments at l temperatures and moderate frequencies as a means to acquir equivalent knowledge of the high frequency viscoelastic aviour of the material.

The apparatus described in this paper has been developed m a method originally used by Nolle(19) and later by lier(10), Iwayanagi and Hideshima(11) and by Deutsch, ff and Reddish.(3) The temperature range extends conously from 20 to 600° K and the frequency coverage is m 25 to about 2000 c/s, measurement being made at crete frequencies depending on the resonant mode of the cimen. In spite of the shortcomings of a resonance thod, the equipment is well suited for industrial research poses in that a large amount of theoretical and practical ormation can be obtained quickly, reasonably accurately l with a minimum of computational effort. It has been d to study mechanical property–chemical structure relationps for a large number of polymers by the "phenomenoical" method, making use of dynamic Young's modulus l internal friction measurements (mechanical loss factor). e discontinuous frequency coverage, characteristic of a onance experiment, is an important though not insuperable ection to the use of the method for deriving distribution ctions from measurements over a frequency range; howr, the latter is not one of our primary aims and the frequency iation available suffices for deriving estimates of activation rgies where necessary.

THE METHOD

The specimen in the form of a thin reed has one end rigidly mped to the vibrating element in an electromechanical nsducer, and the other end free. By applying a sinusoidalquency independent displacement to the clamped end the cimen can be set into transverse vibration. At discrete itation frequencies, various resonance conditions are set and noted from the amplitude response of the free end the specimen which goes through a maximum at resonance. e theory of this method has been discussed in some detail Horio and Onogi(20) who derive corrected expressions for dynamic modulus and mechanical losses of the specimen terms of the resonant frequency and band width of the onance curve. With this equipment three and sometimes ir transverse resonances can be excited in the specimen. e ratio of these resonant frequencies agrees closely with the ios derived theoretically for a "clamped-free" cantilever. the case of the ratio of the first overtone to the fundamental discrepancy between the derived and calculated ratios is ch less than 1% and at higher modes the ratios differ by y 1 or 2% for specimen lengths of between 5 and 6 cm. is experimental evidence, together with a visual observation the cantilever profiles at resonance, virtually rules out the ssibility of the specimen behaving as a "hinged" cantilever. The propagation of compression and torsional waves along specimen and possible spurious transverse vibrations have n considered. The existence of other modes of vibration y lead to a coupling and interchange of vibrational energy ich might significantly influence any conclusions derived lusively from transverse cantilever vibration measurements. ias been assumed that coupling into other modes will be all provided that the physical length of the specimen rating at its highest cantilever frequency is less than $\frac{1}{10}$ of wavelength corresponding to the other unwanted modes vibration. An upper frequency limit (2 kc/s) is set by ue of the self-resonant frequency of the driving unit, at ich frequency, the wavelength of the most probable vanted mode (shear waves) is given by

$$\lambda = (1/2000)\sqrt{[E/2\rho(1+\sigma)]}$$

Assuming Poisson's ratio $\sigma = 0{\cdot}5$ and ρ the specimen density = 1·0 (approximate value for polymers) then λ_{shear} varies between approximately 100 cm and 1 cm for Young's moduli E between 10^{11} dyn/cm^2 and 10^7 dyn/cm^2, this being a typical modulus range for polymers. This means that up to the frequency limit specified (2 kc/s) a 6 cm length specimen may be vibrated in cantilever modes provided the modulus is high, whereas it is inadvisable to operate short cantilevers with low moduli over the entire frequency range. In practice low modulus measurements, usually carried out at high temperatures, are performed at much lower frequencies (less than 100 c/s). In this range it is permissible to use specimens up to 2 cm in length provided the Young's modulus is not less than 10^7 dyn/cm^2.

In order to avoid spurious transverse vibrations the specimens are machined with a rectangular cross-section and excited perpendicular to the long edge. With the thickness-to-width ratio usually used no other transverse modes could be detected.

The amplitude of the free end of the cantilever is observed photoelectrically and the oscillations displayed on a cathode-ray oscilloscope. In this way small strains (10^{-3} skin strain at the clamp) can be employed and no non-linear amplitude effects were observed. A further advantage of this method of observation is the continuous monitoring of the cantilever wave form.

The specimen and transducer are thermostatted in a vacuum, and temperatures are changed by controlled heat transfer from either a refrigerant or hot silicone oil *via* an exchange gas. Thus a large continuous temperature range can be covered very conveniently and efficiently, and by making measurements in a vacuum unwanted air friction is eliminated.

The specimen is suspended vertically in such a way as to facilitate measurements on rubbery materials. In general, it was not possible to detect any differences in the resonance response arising from variations in clamping pressure at the excitation end of the specimen. For very rubbery specimens it was often necessary to mount the polymer in the clamp with a cellulose acetate or other suitable cement.

THE APPARATUS

The electromechanical vibrating unit G (Fig. 1) is an adapted gramophone cutterhead. It consists of a rectangular steel lamina clamped at one edge and free to vibrate at the opposite edge under the influence of a permanent magnetic field perpendicular to the plane of the steel plate. The wire of the coil providing this field is covered with Fluon in order to ensure adequate insulation at high temperatures. A calibrated 1 W audio-frequency oscillator supplies the voltage to this coil and an attenuator has been fitted for use when measuring very low loss materials. The free edge of the vibrating steel lamina is recessed to take the small metal clamp holding the cantilever specimen.

A copper–constantan thermocouple R is attached to the steel lamina in the cutterhead at the point where it is rigidly clamped. This indicates the temperature of the clamped end of the specimen to within 0·2° K and stability experiments carried out at various temperatures showed that a temperature difference of 0·5° K along the length of a specimen was the maximum observed at any temperature after an interval of 10–15 min to establish an equilibrium. The method of attachment does not noticeably influence the motion of the vibrating system. Electrical leads from transducer and thermocouple are brought to the inside of the support tube E through the holes M and leave through the vacuum seal A

at the top of the suspension. The cutterhead unit is attached to a long hollow glass tube (length, 20 cm, inside diameter, 2·9 cm, external diameter, 3·0 cm) the upper end of which opens out into a male B.40 cone and is rigidly clamped above this. The purpose of this type of suspension is to locate the specimen and transducer in a vacuum space and ensure that very little heat can be exchanged between the specimen and room temperature by conduction along the support. The main mechanism for heat transfer to the specimen in order to change its temperature is by conduction through an exchange gas (hydrogen or nitrogen) which can be passed into the space marked *D*.

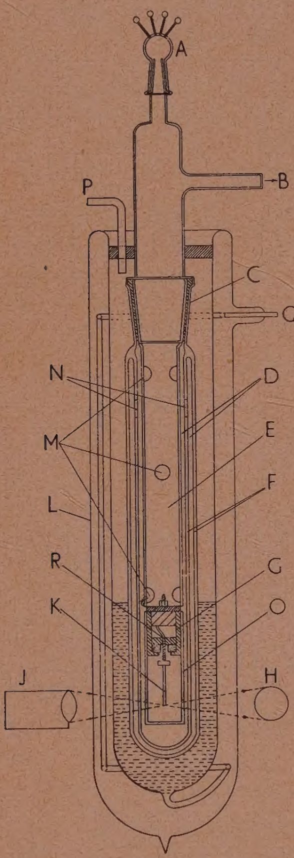


Fig. 1. Transducer assembly

A, vacuum seal for electrical leads; *B*, to vacuum system; *C*, glass cone joint; *D*, vacuum or exchange gas space; *E*, glass support tube for transducer; *F*, double-walled glass vacuum jacket; *G*, transducer (rotated through 90° to show details of construction); *H*, photoelectric cell; *J*, light source; *K*, specimen; *L*, Dewar vessel; *M*, pumping holes in main support tube; *N*, holes in the inner wall of *F*; *O*, radiation shield; *P*, pumping line; *Q*, inlet to built-in syphon tube.

Surrounding the specimen is a silvered brass radiation shield *O* which is in thermal contact with the transducer *G*. Two small holes are bored in it in order to view the tip of the specimen. The purpose of this shield is to reduce energy transfer to the specimen by radiation from the walls of the vessel *F*. This can be a serious source of temperature instability when the space *D* is evacuated for it can be shown that an unshielded specimen at 77° K exposed to a wall temperature in *F* of 290° K will heat up at the rate of about 50°/min.

The vessel *F* is a double-walled container which seals at the B.40 cone *C*. The annular space is open to the interior through a series of holes *N* and the whole is fully silvered on all surfaces with the exception of a slit 1 × 6 cm at the lo end through which the specimen may be viewed. Excha gas may be introduced into the spaces *D* *via* the holes N the main support tube which connects to either a vacu system or gas cylinder at *B*. It is this gas which trans "heat" or "cold" from the liquid in the Dewar vessel *L* the transducer and specimen. The internal wall of the ve serves to reduce the amount of radiation falling on radiation shield *O* from the external wall directly in cont with the liquid in *L*.

The remainder of the vacuum equipment is a conventio two-stage pumping system consisting of backing pump, liq air trap and a double-stage mercury diffusion pump. T other items are standard equipment and are indicated in Fig

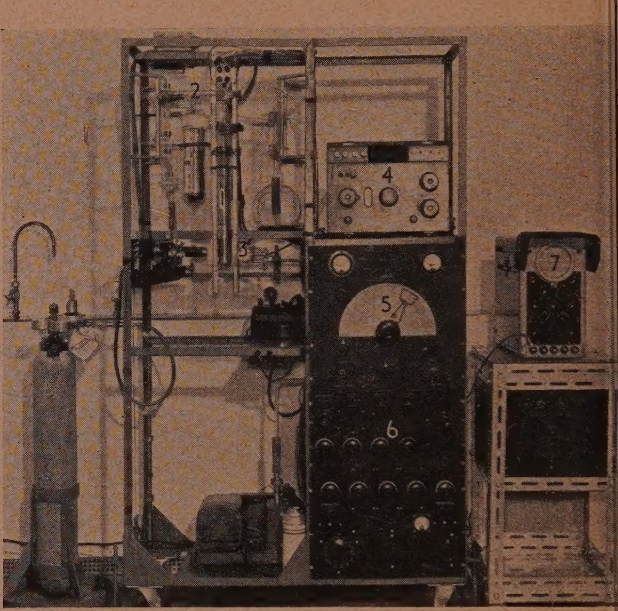


Fig. 2. General view of equipment

(1) transducer assembly; (2) vacuum system; (3) photoelectric detector; (4) potentiometer; (5) audio-frequency oscillator (6) auxiliary electrical equipment; (7) oscilloscope.

In order to observe the motion of the specimen a li source of white light (the filament of a galvanometer lamp) focused on its tip through a glass infra-red filter and windo in both the Dewar vessel *L* and the vacuum jacket *F*. T beam diverging from this focus falls on a gas-filled pho electric cell placed outside the apparatus. The light sour a conventional 4 V, 8 W lamp, is mounted on a fine adju ment rack and pinion device which enables it to be adjust in three mutually perpendicular directions. This and photocell are both rigidly connected to the same steel pl in order to avoid relative movement.

It is arranged that approximately a third of the total ima of the line source is interrupted by the tip of the cantile when it is hanging vertically at rest. When the reed is set i vibration a further area of the focused line source is cut and the resulting light intensity falling on the photoelect cell varies sinusoidally in phase with the oscillations of reed. Provided the illuminated length of the specimen small in comparison with its whole length, the amount light falling on the photoelectric cell is proportional to angular displacement of the specimen.

EXPERIMENTAL

eneral procedure. The polymer specimen of rectangular s-section 0·1 × 0·15 cm is cut to a length of between nd 6 cm depending on the particular frequency range ired. Apart from measurements at overtones, the ration of specimen dimensions is the only way of changing frequency range of a resonance vibration experiment at ven temperature. It is mounted vertically in a small steel np, the stem of which is in turn clamped to the vibrating nent in the transducer, both clamp and specimen being ovable together. The radiation shield is placed around specimen and the double-walled glass vacuum jacket is fitted over the transducer assembly and sealed at the) cone.

. Dewar vessel containing either liquid nitrogen, liquid rogen or silicone oil, depending on whether the experiment o be conducted at temperatures below or above room perature, is then put around the vacuum jacket. This var vessel is also made with a double-viewing slit and the le assembly is alined until the specimen tip can be seen e clearly from either side. The light source and photocell em are then adjusted until the vibrations of the cantilever perpendicular to the light beam.

he signal from the photocell is fed directly into the lifier of an oscilloscope. To the front of the cathode-ray e a perspex disk is fitted on which four parallel horizontal ngs are engraved. The ratio of the separation of the er pair of lines to the distance between the inner pair is $\sqrt{2}$. en the specimen has been brought to resonance, the gain he amplifier is adjusted so that the displayed sine wave ches the outer markings on the screen. The oscillator uency is then adjusted on both sides of a resonance until amplitude of the signal coincides with the inner rulings; frequency readings then give the half-power points of the nance curve, at which the amplitude has fallen to $1/\sqrt{2}$ he resonant amplitude, and from these frequencies and the nant frequency the mechanical losses and dynamic lulus can be deduced.

he bandwidth of the resonance curve (i.e. the frequency erence between the half power points) divided by the nant frequency f_0 is a measure of the internal friction, and dynamic Young's modulus is obtained from the following ression:

$$E = 48\pi^2 \rho l^4 f_0^2 / m^4 t^2$$

ere

ρ = density of the specimen;
l = length of the specimen;
t = thickness of the specimen in the plane of the vibration;
m = parameter descriptive of the mode of vibration;
= 1·875 for the fundamental mode;
= 4·694 for the first overtone mode;
= 7·855 for the second overtone mode.

s possible to identify the required overtone mode of nsverse vibration by adjusting the time-base frequency il a single sine wave trace is set up at the fundamental nant mode of vibration. If the time base setting is now untouched and the oscillator frequency altered until the overtone is excited, a stationary trace consisting of roximately 6½ waves will appear on the screen. Similarly, he correct second overtone is excited, 17½ waves will ear. These figures represent the approximate ratios of first and second overtone resonant frequencies to the damental resonant frequency of the cantilever.

he temperature of the clamped end of the specimen is sured with the thermocouple immediately a measurement of the resonant frequency and band width has been taken, the thermocouple being previously calibrated at the normal boiling points of hydrogen (20·4° K), nitrogen (77·3° K), propane (231·1° K) and water (373·2° K), the sublimation point of carbon dioxide (194·7° K) and at the normal melting point of ethyl alcohol (155·9° K). The temperature is altered by filling hydrogen or nitrogen exchange gas into the vacuum jacket to a pressure of approximately 10^{-3} mm of mercury, thus allowing thermal energy to be interchanged between the specimen and transducer and the constant temperature bath in the Dewar vessel. When the cutterhead assembly has reached the required temperature, the space D containing the exchange gas is evacuated for about ten minutes which is long enough to permit the thermally isolated system to reach temperature equilibrium, usually one degree or so different from that existing when the system was initially evacuated. The stability of the temperature now depends on the amount of heat conducted down the glass supporting tube, the top end of which is at room temperature, and also on the thermal capacity of the specimen transducer assembly. Assuming that the transducer can be considered thermally as a block of steel, of known mass and specific heat, it is easy to estimate the temperature rise of the thermally isolated system due to heat conduction down the glass support. At the normal boiling point of liquid nitrogen the estimated temperature rise is about 0·80° K/min, this figure representing the thermal stability of the specimen at 77° K. In practice, the stability is very much better than this figure would indicate, as at the lowest temperature the Dewar vessel is almost filled with liquid nitrogen and the clamped end of the transducer assembly is at a temperature considerably lower than 290° K.

To alter the temperature again, the exchange gas procedure is repeated until finally the specimen is either heated or cooled to the temperature of the liquid in the outer Dewar vessel; the temperature range can be traversed in the reverse direction back to room temperature.

Polymers have low thermal diffusivities, and it is, therefore, of interest to know their thermal relaxation time. This gives an indication of the time it takes for a specimen of given dimensions to reach temperature equilibrium with an external thermal bath. It must not be confused with the viscoelastic relaxation times. Knowledge of this time constant enables one to estimate the minimum time required for the exchange gas to interchange energy between the bath and specimen. For the usual sample thickness of 0·040 in. this time is less than a second at room temperature.

The temperature dependence of the mechanical properties of polymers can be utilized to check temperature stability. If the cantilever is vibrated in the fundamental mode, then the frequency of the resonance maximum is a fairly sensitive indicator of any changes in specimen temperature. It was, in fact, the observation of this shift in resonant frequency at an apparently constant temperature as measured at the clamp that drew attention to the importance of radiation effects.

A certain amount of energy is dissipated during the cyclic deformation of a specimen which exhibits internal friction. This appears as heat and raises the temperature of the specimen. However, no effect could be detected by the resonant frequency stability method described above and a calculation for polythene at 100 c/s and $\tan \delta = \Delta f / f_0 = 0{\cdot}08$ gives a value for $d\theta/dt$, the rate of rise of temperature = 0·004° K/s. Since the actual time taken to do a measurement is of the order of ten seconds, this effect is very small. This heating can give rise to considerable errors if the losses are very large. (Cf. the transitions in natural and synthetic rubbers.)

Refrigeration technique. The general outline of temperature control and some factors affecting thermal stability have been given above. However, a number of points of experimental interest arise when using liquid nitrogen and liquid hydrogen. These liquids, continually evaporating owing to unavoidable heat influxes, give off cold vapours which cool the upper end of the glass support tube, thereby reducing the temperature gradient and heat influx due to conduction. The liquid nitrogen level is usually kept just below the bottom tip of the specimen for temperatures down to 180° K, but for very low temperatures, in order to avoid a long cooling time, it is better to fill the Dewar vessel about two-thirds full. Superheating of the liquids can give rise to the evolution of gas bubbles in the bulk of the refrigerant which can be very troublesome if they rise up past the viewing aperture. The use of very clean glassware and careful positioning of the external Dewar vessel usually ensures freedom from this trouble, but persistent bubbling in liquid nitrogen can be temporarily inhibited by blowing hydrogen gas through it.

For temperatures below the normal boiling point of liquid nitrogen, two techniques have been employed. With a high speed, large capacity vacuum pump, it is possible by pumping through the pumping line *P* (Fig. 1) to reduce the vapour pressure above the nitrogen and so reduce its temperature by some 14° K down to the triple point at 63° K and 9·6 cm pressure. As solid nitrogen is opaque, it is necessary to arrange that only the lower half of the Dewar vessel contains the solid, otherwise viewing the vibrations becomes very difficult. The other method, using liquid hydrogen, calls for some specialized techniques, the main one being the change over from the liquid nitrogen stage, which for obvious economy reasons must be used as a precoolant. For this purpose use is made of the special syphon *Q* built into the Dewar vacuum space and opening into the bottom of the Dewar vessel. With this arrangement it is possible to exhaust the liquid nitrogen through the syphon using a slight overpressure of hydrogen gas through the pumping line *P* which eventually "flushes out" all traces of gaseous nitrogen. At this stage liquid hydrogen can be syphoned into the bottom of the Dewar vessel and no trouble can arise due to the freezing of any residual nitrogen gas. The copper–constantan thermocouple behaves reproducibly down to 20° K provided it is not subjected to any mechanical strains and either hydrogen or helium may be used as an exchange gas for heat transfer. With the present experimental arrangement it is possible to do one complete experiment in the liquid hydrogen range, i.e. cooling from 77 to 20° K and warming up over the same range, with approximately one litre of liquid hydrogen.

High temperature technique. A silicone oil is used for experiments up to 600° K. The oil is filled in to the level of the transducer, and heated by a single coil of Nichrome wire (of 70 Ω resistance) loosely surrounding the lower end of the vacuum jacket. It was found convenient to employ a power input of approximately 150 W in 50 cm³ of oil, this being applied intermittently for one or two minutes just prior to letting in the exchange gas. The use of a variable heating element should simplify temperature stabilization, as the oil bath temperature could then be adjusted more easily. In the present arrangement of the apparatus there is no provision for thermostatting the temperature of the oil and the adiabatic vacuum technique, with slow heat efflux to the supported end of the transducer assembly, is used.

CONCLUSIONS

The apparatus has been used extensively to study the influence of the molecular structure of high polymers on their dynamic mechanical behaviour. It is simple to operate and under normal conditions a temperature run from 7
400° K can be completed in a day. The actual and theore
performances of the apparatus compare very well. Mos
the thermal calculations were based on the worst poss
operating conditions, whereas in fact the observed ex
mental conditions, in particular thermal stability of
transducer, were considerably better. The estimated accu
of the loss measurements is ±5%; the dynamic moduli
accurate to better than 5%. Taking into consideration
purpose for which this apparatus was originally desig
i.e. the correlation of anelastic dispersion peaks and mod
changes with chemical structure, such an order of accura
quite satisfactory. Some typical experimental results wi
reported in a subsequent publication.(21)

ACKNOWLEDGEMENTS

The author wishes to thank his colleagues for helpful
cussions and is particularly grateful to Miss D. A. Tho
for her assistance with the assembling and operation of
apparatus, and to Mr. N. Payne for his help with the de
and construction of the glass work.

REFERENCES

(1) Ferry, J. D., and Fitzgerald, E. R. *Proceed*
Second International Congress on Rheology, p.
(London: Butterworths Scientific Publications, 19
(2) Alfrey, T. *Mechanical Behaviour of High Polym*
p. 127 (New York: Interscience Publishers Inc., 19
(3) Deutsch, K., Hoff, E. A. W., and Reddish,
J. Polymer. Sci., **13**, p. 565 (1954).
(4) Heyboer, J., Dekking, P., and Stavermann, A
Proceedings Second International Congress on Rheol
p. 123 (London: Butterworths Scientific Publicati
1954).
(5) Schmieder, K., and Wolf, K. *Kolloid Z.*, Nos.
p. 149 (1953).
(6) Schwarzl, F., and Stavermann, A. J. *Physica*,
p. 791 (1952).
(7) Phillippoff, W. *Phys. Rev.*, **86**, p. 644 (1952).
(8) Mason, W. P., Baker, W. O., McSkimin, H. J.,
Heiss, J. H. *Phys. Rev.*, **73**, p. 1074 (1948).
(9) Ballou, J. W., and Smith, J. C. *J. Appl. Phys.*,
p. 493 (1949).
(10) Hillier, K. *Proc. Phys. Soc.* [*London*] *B.*, **62**, p.
(1949).
(11) Iwayanagi, S., and Hideshima, T. *J. Phys.*
Japan, **8**, p. 368 (1953).
(12) Lethersich, W. *E.R.A. Technical Report L/T*
(Electrical Research Association, 1952).
(13) Hillier, K. W., and Kolsky, H. *Proc. Phys.*
[*London*] *B*, **62**, p. 111 (1949).
(14) Lethersich, W. *Brit. J. Appl. Phys.*, **1**, p. 294 (195
(15) Marvin, R. S. *Proceedings Second International*
gress on Rheology, p. 156 (London: Butterwo
Scientific Publications, 1954).
(16) Fitzgerald, E. R., and Ferry, J. D. *J. Colloid Sc*
p. 1 (1953).
(17) Fitzgerald, E. R., and Ferry, J. D. *J. Colloid Sc*
p. 224 (1953).
(18) Ferry, J. D. *J. Amer. Chem. Soc.*, **72**, p. 3746 (1
(19) Nolle, J. *J. Appl. Phys.*, **19**, p. 753 (1948).
(20) Horio, M., and Onogi, S. *J. Appl. Phys.*, **22**, p.
(1951).
(21) Thomas, D. A., and Robinson, D. W. *Brit. J.*
Phys., to be published.

n optical interferometer method of calibrating a crystal gauge for the measurement of sound wave transients

By G. J. Barber, B.Sc., Grad.Inst.P., Physics Department, Imperial College of Science and Technology, London

[*Paper first received* 30 *September, and in final form* 26 *October*, 1954]

A small barium titanate crystal is used for the measurement of large amplitude sound pulses in a tube and a method of directly calibrating the crystal by means of a Mach–Zender interferometer is described.

easurements of finite amplitude sound pulses and other nsient phenomena occurring in a shock tube have been ide, using piezoelectric crystals(1,2) and optical interfero- eters.(3) Since optical interferometers are absolute struments they may be used to calibrate crystal gauges, d the present paper describes an example of this ocedure.

In recording a sound pulse in a tube it is desirable that e measuring device should present only a small obstacle to e sound waves and should have a good high-frequency sponse; it should also possess as high a sensitivity as ssible. To meet these requirements use was made of the operties of barium titanate in the form of a radially- larized hollow cylinder $\frac{1}{16}$ in. long, $\frac{1}{16}$ in. external diameter d with a wall thickness of $\frac{1}{100}$ in. The difficulty of ounting such a small specimen was satisfactorily over- me in the manner illustrated in Fig. 1. A polythene disk 013 in. thick was cemented to each end of the crystal and e larger of the two disks was then cemented to the face of 1 in. diameter brass block; connexion to the inside of the ystal was by means of a spring contact soldered to a wire axial with the crystal and passing through the block and ne of the polythene disks; connexion to the outside was ith a layer of Aquadag. The brass block was then placed a 1 in. diameter hole in the side of the observation tube that its inside face was flush with the tube wall.

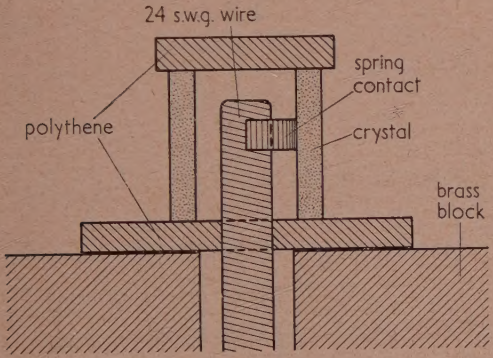


Fig. 1. Mounting of crystal on brass block

The capacity of the crystal was about 200 pF, so in order ot to attenuate the low frequencies an input impedance of least 20 MΩ was necessary. This was achieved using a thode follower as the first stage of amplification, the signal om this was then suitably amplified and displayed on a thode-ray tube.

The optical interferometer used for measuring the sound pulses, produced by a loudspeaker at the end of the tube, has been described by Timbrell(3) and later by Embleton,(4) but for the sake of completeness its method of use will be briefly described here. The instrument was of the Mach–Zender type arranged to have one of its interfering light beams passing through the observation tube; the fringe pattern was adjusted to consist of a few vertical white light fringes and this was focused on to a screen with a very narrow vertical slit. The light passing through the slit was recorded by a photo-multiplier cell, so that the changing of the air density in the tube caused the fringes to move and hence gave rise to an electrical output from the cell. The amplification of the signal from the cell was d.c. so a direct calibration using known static pressures was possible, and using this, absolute pressure time curves for the sound pulses could be obtained.

The recordings of the crystal were compared with the pressure-time curves obtained by the above interferometer method. A typical voltage-time oscillogram using the crystal as detector is shown in Fig. 2; the peak amplitude in this case corresponds to a 3 cm deflexion on the oscilloscope screen which is equivalent to about 5 mV output from the crystal obtained with a sound pressure of 5 cm of mercury. This sensitivity, which is about 0·075 V/b, is a few per cent below the sensitivity of the crystal alone, due to the shunt capacity of the leads and cathode follower input. This effect is small since these capacitances are of the order of a few picofarads, whereas the crystal, as already stated, has a capacity of about 200 pF. The agreement in shape between the pulses recorded by the two methods was excellent, indicating that the crystal had a frequency response adequate for this type of work. Correlated values of peak excess pressure, for various pulses as recorded by the interferometer, and the peak deflexion on the oscilloscope screen produced by the crystal are given in the table.

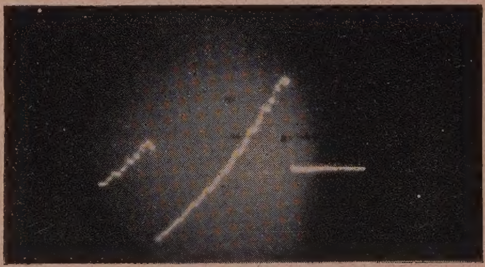


Fig. 2. Oscillogram of sound pulse as recorded by the crystal; peak amplitude is about 5 cm of mercury; the time between shock fronts is 400 μs

Peak pressure (P) using interferometer (cm of mercury)	Peak deflexion (D) using crystal (arbitrary units)	Ratio P/D
5·45	1·54	3·55
5·04	1·40	3·59
4·55	1·31	3·47
4·46	1·26	3·54
3·97	1·10	3·60

REFERENCES

(1) Becker, J. V. *J. Appl. Phys.*, **21**, p. 619 (1950).
(2) Werth, G. C., and Delsasso, P. G. *J. Acoust.* *Amer.*, **26**, p. 1 (1954).
(3) Timbrell, V. *Nature* [*London*], **167**, p. 306 (1951).
(4) Embleton, T. F. W. Ph.D. Thesis, University of Lon 1952.

A machine for the measurement of rolling friction

By J. Halling, B.Sc.(Eng.), Department of Mechanical Engineering, University of Liverpool

[*Paper received* 6 *October*, 1954]

The paper describes a machine which has been developed for the measurement of the resistance to rolling under a range of applied loading. The machine is essentially a compact compression machine in which the rolling friction is determined by the principle of the inclined plane. It has a range of loading of 20–1000 lb with a sensitivity of ±½ lb. A simple modification enables the machine to be used over a greater load range but with a reduction in sensitivity. The same principles could be adopted where it is desired to measure small displacing forces acting on a system under load.

The small forces necessary to overcome rolling resistance may be readily determined by the application of the principle of the inclined plane. This technique was used by Reynolds,(1) and more recently by Bikerman,(2) during investigations into the mechanism of the rolling friction of unloaded rolling elements. The testing machine described below was designed to extend the technique to the case when a compressive load is applied to the rollers.

With the machine shown in Fig. 1 it is possible to apply a load to the rollers from 20 to 1000 lb but a small modification substantially increases this range. The compression system consists essentially of three blocks *A*, *B* and *C* which are separated by pairs of rollers *D* resting between identical test plates *E*. The upper block *A* is fixed in relation to the lower block *C* by two end plates *F* such that it may only move in the direction of the applied load. The two pairs of ro enable the central block *B* to have a limited movem transverse to the direction of the compressive load. Spher contacts resting in cone seatings ensure the alinement of axis of loading. The load is applied by screwing the nu with the aid of tommy bars, along a screw which is preven from rotating by a pin locating in a slot cut along the sc

The magnitude of the applied load is indicated by measu the deflexion of the beam *H* shown in Fig. 2. This bea simply supported on two rollers *J* which are free to rotat oversize holes drilled in the side plates of the loa mechanism assembly. The position of the beam is loca by two pins passing through countersunk clearance hole the beam. Deflexion of the beam is recorded by a dial ga reading 1/10000 in. per division, fixed between the extens pillars *K*. A spindle lifter is fitted to this gauge, and contact surface on which the anvil of the gauge rests is lap to preclude errors caused by sticking at this surface.

For the beam used in this machine (steel having a y stress of 60 t/in.^{2} and a cross-section of 2 in. × $\frac{3}{8}$ in.) the ra of loading is approximately 20–1000 lb with a sensitivity approximately ½ lb per division. The lower limit of the l range arises from the static load due to the mass of th parts of the machine directly supported by the rollers.

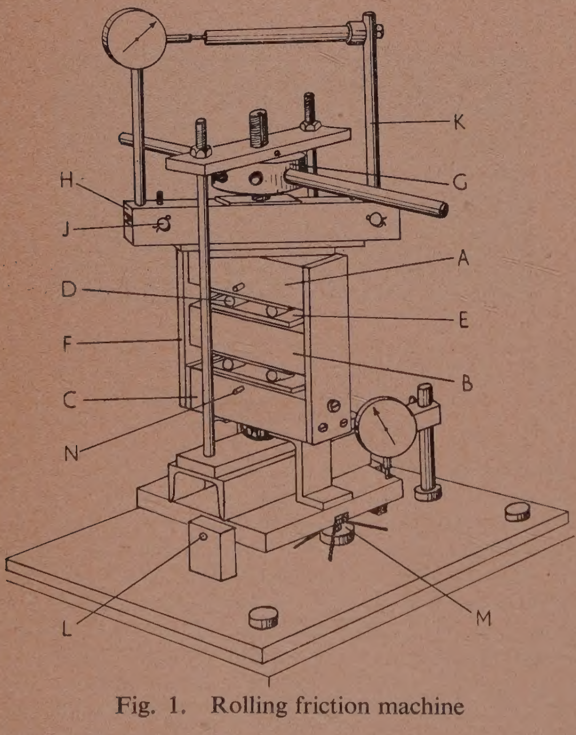


Fig. 1. Rolling friction machine

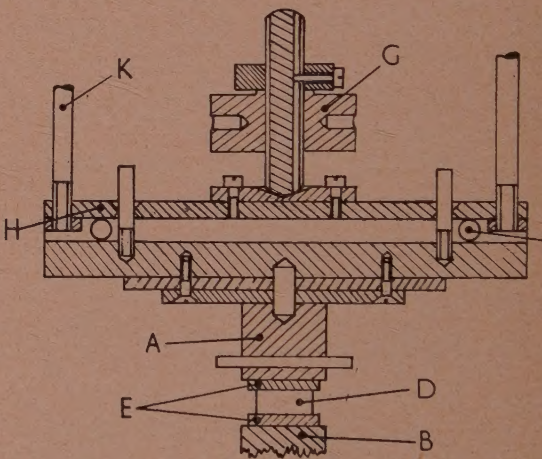


Fig. 2. Details of loading mechanism

crease in the load range may be obtained by using a stiffer am but would result in a reduction in the sensitivity.

The calibration of the beam is carried out in a standard ting machine and gives a substantially linear characteristic shown in Fig. 3; the shape of the characteristic depends on e geometric form of the surface on which the dial gauge vil rests. The slight hysteresis observed for the reversal of ading is probably due to sticking of the rollers supporting e beam.

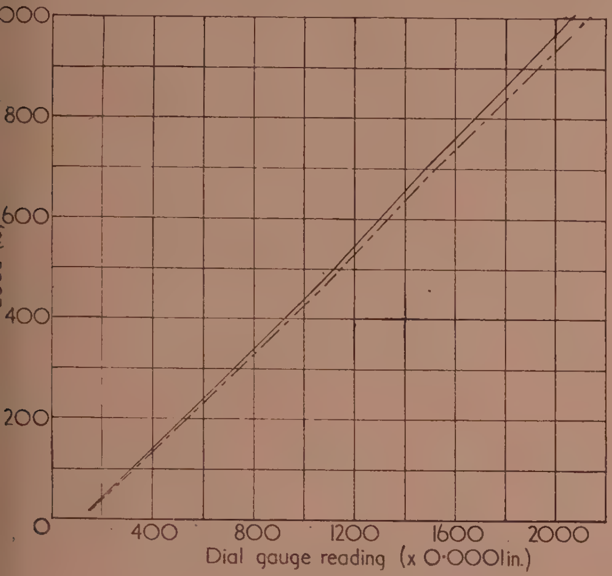


Fig. 3. Calibration curve for load indicating mechanism

In Fig. 1 it will be seen that the whole of the compressive stem is mounted on a base plate which is pivoted at *L*. A all screw jack *M* tilts the system, the angle of inclination ing recorded on a second dial gauge (0–1 in. travel with 001 in. per division). The central block *B* is displaced en the inclination is such that the gravitational force ing on the moving parts is sufficient to overcome the rolling istance. The machine thus gives a direct measure of the ctional resistance for any value of applied load.

It is essential that the rollers be initially set with their axes rallel and equally disposed on either side of the axis of ading. For this purpose two pins *N*, Fig. 4(*a*), are fitted the blocks *A* and *C* respectively, such that they are in line h, and transverse to, the axis of loading. Two plates *O*, e on each side of the assembly, register on these pins and o locate the protruding tongues of the setting gauges *P*. e rollers are pressed into contact with these gauges and a all compressive load is applied to hold the system. The ating plates *O* are then removed and the setting gauges y be raised and withdrawn as shown in Fig. 4(*b*). A ies of spacing pieces *Q*, of various thicknesses, are used set the operational faces of the setting gauges to the ropriate height for the diameter of the rollers which are ng tested.

An example of typical results which are obtained with the chine are shown in Fig. 5. The curve shows the relation- p between the rolling resistance and the applied load when n. diameter, 1 in. long, steel rollers are rolled between el surfaces. A fuller account of the experimental results l be published in due course.

The machine is essentially a compact compression machine ich has been designed to provide a measure of rolling friction by the inclined plane principle. The principles of the machine could be readily incorporated into the design of apparatus for the measurement of small transverse forces producing displacements of a loaded system.

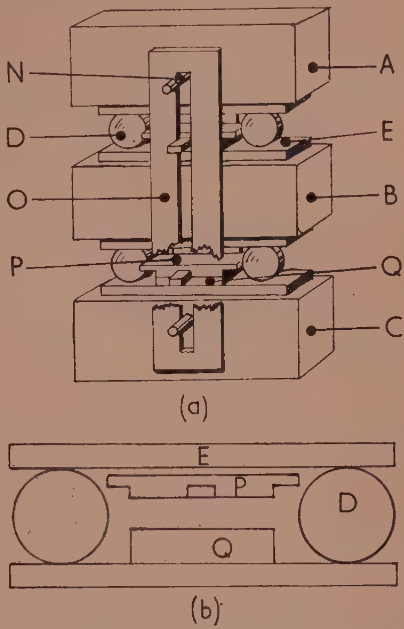


Fig. 4. (*a*) Method of setting rollers. (*b*) Removal of roller setting gauge

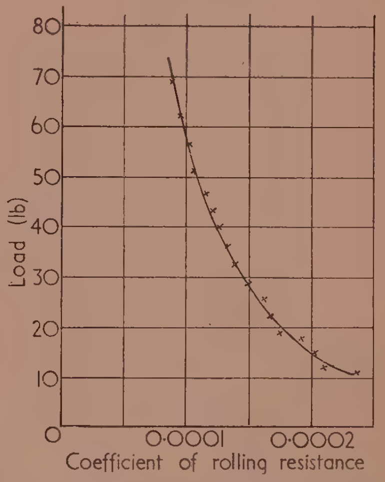


Fig. 5. The relationship between load and rolling resistance when $\frac{1}{2}$ in. diameter, 1 in. long, steel rollers are rolled between steel surfaces

ACKNOWLEDGEMENTS

I would like to express my thanks to Mr. F. Robinson of the Royal Military College of Science for his advice and suggestions during the design of this machine. I would also like to thank Professor H. Ford of the Imperial College of Science and Technology for his help and suggestions during the application of the machine to the experimental determinations.

REFERENCES

(1) Reynolds, O. *Phil. Trans*, **166**, p. 155 (1876).
(2) Bikerman, J. J. *J. Appl. Phys.*, **20**, p. 971 (1949).

Infra-red filters using evaporated layers of lead sulphide, lead selenid and lead telluride

By J. G. N. Braithwaite, M.A., Radar Research Establishment, Great Malvern, Worcs.

[*Paper received* 31 *August*, 1954]

The optical properties of these layers are shown to differ from those of evaporated and chemical layers reported previously but to resemble those of single crystals of the materials. The use of these layers as optical filters which absorb visible and near infra-red radiation but transmit at wavelengths longer than about 2·9, 4·2 and 3·8 μ respectively is described.

A number of papers have appeared during the last three or four years concerning the absorption spectra of lead sulphide, lead selenide and lead telluride. The work of Paul, Jones and Jones,⁽¹⁾ of Gibson,⁽²⁾ and of Avery⁽³,⁴⁾ has established the general nature of the absorption of these materials in the crystalline state and these writers agree fairly closely on the values of the absorption constants and their spectral variation. All the materials show very strong absorption in the visible region of the spectrum ($\simeq 10^6$ cm^{-1}) with marked absorption edges lying between 0·5 μ and 1·0 μ and with a long-wave tail absorption ($\simeq 10^4$ cm^{-1}) ending in a sharp secondary absorption edge. The wavelength of this secondary edge corresponds to the long-wave photoconductive limit of the material when at the temperature of the specimen used for the absorption measurements.

On the other hand, measurements of the absorption spectra of these materials, in the form of evaporated and chemically deposited layers by Gibson,⁽⁵⁾ while showing the main absorption edge, exhibited long-wave tail absorption which was quite different in character from that of the single crystals described above. In particular, he found no evidence of secondary edges at the wavelengths corresponding to the photoconductive cut-offs.

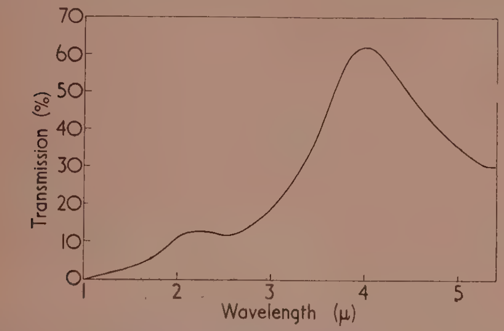


Fig. 1. Transmission spectrum of a layer of lead sulphide, thickness 0·5 μ

Recently, however, Vernier⁽⁶⁾ has made layers of lead sulphide by chemical deposition and by "distillation" which show approximately the same absorption spectra as crystalline lead sulphide. Independently, we have studied evaporated layers of all three salts, lead sulphide, lead selenide and lead telluride. Under certain conditions these have the absorption spectra of the corresponding single crystals, showing to a marked degree the secondary absorption edges and also thin-film interference bands in the region of low absorption beyond these edges (see Figs. 1, 2 and 3).

These layers have been developed because of their value as infra-red filters which transmit the longer wavelength radiation but reject the visible and near infra-red radiation. For example, one of our lead sulphide filters has been used by Sayce⁽⁷⁾ at the National Physical Laboratory in place of the relatively expensive and cumbersome fore-prism in an expe mental infra-red grating spectrometer.

Attempts to make filters from single crystals of the materials were generally unsuccessful, as with most of t material available we were unable to work slices which we thin enough to show sufficient transmission beyond t

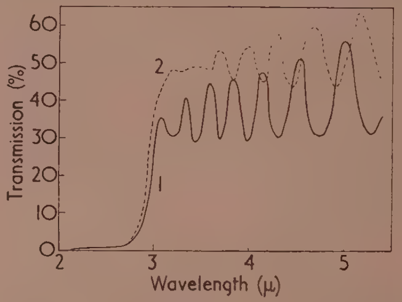


Fig. 2. Transmission spectra of a lead sulphide layer

(1) layer of lead sulphide, thickness 6 μ; (2) layer (1) after coating with a layer of selenium of optical thickness designed to reduce interference at 3·2 μ.

secondary absorption edge. High transmission was obtaine with slices of the purest galena (natural lead sulphide), b it seems that such galena is very rare.

In most filter applications the interference bands shown b these thin layers are inconvenient, and it has been foun possible to remove the bands in chosen wavelength regions b applying a blooming layer of selenium to the free surface the layer. The refractive index of selenium is 2·3 compare with 4·2 for lead sulphide, 4·5 for lead selenide and 5·5 f lead telluride,⁽⁴⁾ so it forms a reasonable match for layers any of these materials. The effect of the selenium layer ma be seen on comparing the two curves of Fig. 2.

The optical thickness of a layer may be calculated from t wavelengths of the maxima and minima in its absorptio spectrum. The geometrical thickness can then be obtaine by dividing by the refractive index of the layer. The valu of the thickness given on Figs. 1, 2 and 3 were obtained fro the refractive indices of the bulk materials. For wavelengt in the transparent region the refractive index and absorptio

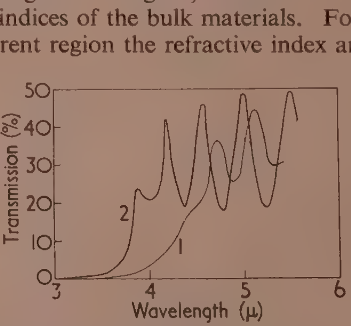


Fig. 3. Transmission spectra

(1) lead selenide layer, thickness 6·8 μ; (2) lead telluride layer, thickness 5 μ.

efficient of a layer can be calculated from the measured nsmission at the interference maxima and minima. The ractive index calculated in this way is generally rather wer than the value for the bulk material. This discrepancy uld be explained by roughness of the surface of the layer d variations in the thickness of the layer.

There is an optimum layer thickness for a filter in which arpness of transition and maximum discrimination between e absorbing and transmitting regions are required: too thin layer leads to too high a transmission on the short-wavegth side of the edge, while too thick a layer leads to too eat an absorption in the transmitting region. Layers of itable thickness such as those of Fig. 2 have been obtained trial and error.

The transmission spectra of a few layers have been measured temperatures other than ambient. The results indicate that e wavelengths of the secondary absorption edges show the me changes with temperature as the photoconductive limits the material. Gibson(2) had previously demonstrated the me result for these materials in crystal form. For example, e temperature coefficient for lead telluride layers at room nperature is $-0{\cdot}007\ \mu/^{\circ}\mathrm{C}$, the coefficient being less at gher temperatures and greater at lower temperatures.

These filters are not yet manufactured commercially, but rangements for this are being made. A few of the filters have been made for inclusion in infra-red spectrometers in a number of research laboratories and a small number might be supplied to meet urgent needs until they are available commercially.

ACKNOWLEDGEMENTS

Acknowledgement is made to the Chief Scientist, Ministry of Supply, and to the Controller, Her Majesty's Stationery Office, for permission to publish this paper. Crown copyright reserved.

REFERENCES

(1) Paul, W., Jones, R. V., and Jones, D. A. *Proc. Phys. Soc.* [*London*] *B*, **64**, p. 528 (1951).
(2) Gibson, A. F. *Proc. Phys. Soc.* [*London*] *B*, **65**, p. 378 (1952).
(3) Avery, D. G. *Proc. Phys. Soc.* [*London*] *B*, **66**, p. 133 (1953).
(4) Avery, D. G. *Proc. Phys. Soc.* [*London*] *B*, **67**, p. 2 (1954).
(5) Gibson, A. F. *Proc. Phys. Soc.* [*London*] *B*, **63**, p. 756 (1950).
(6) Vernier, P. *J. Phys. Radium*, **14**, p. 175 (1953).
(7) Sayce, L. A. Private communication (1954).

---

he production of accurate linear scales by means of the Merton nut

By L. A. Sayce, M.Sc., Ph.D., F.R.I.C., F.Inst.P., National Physical Laboratory, Teddington, Middlesex

[*Paper received* 27 *July*, 1954]

A dividing engine is described for making linear scales of unusual accuracy. The scale is engraved photographically upon a plate carried by a Merton integrating nut riding upon a cylinder bearing a very fine screw thread. The cylinder is carried by bearings in which it is restrained from longitudinal movement by applying the principle of the Merton nut to a "thread" of zero lead.

is customary for linear scales to be generated by means of a viding engine in which the working blank is advanced ermittently by a lead-screw and after each advance is scribed by a tool moving in a constant plane perpendicular the lead-screw.

Linear scales prepared in this way invariably exhibit riodic errors because of inevitable slight imperfections in e lead-screw, its thrust bearing, division plate and other mponents of the mechanism. Such scales also exhibit ndom errors due, in part, to the impossibility of maintaining eat constancy in the lubrication of a mechanism in which e moving parts are in intermittent and reciprocating otion.

Experience at the N.P.L. in the ruling of helical diffraction atings by the agency of the Merton resilient nut* suggested at these sources of error could be eliminated by a device ploying the following principle.

PRINCIPLE OF OPERATION

A metal cylinder *A*, Fig. 1, is mounted horizontally near its ds in two cork-lined, spring-clamped bearings *B*. The rtion of the cylinder clamped by one bearing is smooth; e portion clamped by the other bearing is inscribed with a ge number of shallow parallel grooves *C*. These grooves e penetrated by the cork lining of the bearing under the essure of the clamping spring and the cylinder can thus be rotated without longitudinal movement. In other words, the grooved cylinder and cork-lined bearing constitute a very effective "thrust bearing."

The greater portion of the length of the cylinder, lying between its two bearings, is inscribed with a fine helix *D*, of some hundreds or thousands of turns per inch, and to this helix is clamped a cork-lined, spring-clamped nut *E*, free to move from end to end of the helix when the cylinder is continuously rotated. The upper portion of this nut is fashioned into a frame carrying an elongated photographic plate *F*, parallel to the axis of the cylinder, and a lens *G* is rigidly mounted adjacent to the plate and normal to it. A roller *H*, mounted near the lens, bears upon the plate and serves both to maintain a constant separation between the plate and the lens and also to prevent rotation of the nut. At the side of the lens remote from the plate and at the conjugate focus to the plate is mounted a narrow slit *J*, and adjacent to the slit on the side remote from the lens a xenon flash tube *K*, which emits a brief flash of light when suitably triggered. The triggering circuit is normally completed at every rotation of the helix by means of a cam and switch attached to the driving mechanism.

In this manner, continuous rotation of the cylinder produces, by interaction of the helix *D*, and nut *E*, continuous advance of the photographic plate and the flashing of the flash tube produces a series of reduced images of the slit upon the photographic plate, the images being thus separated one from another by a distance equal to the pitch of the helix. Further, by reason of the effectiveness of the thrust bearing in preventing end movement of the cylinder and the effectiveness of the resilient nut in eliminating periodic error, the sequence of slit images constitutes a scale of unusual accuracy.

---

* Merton, Sir Thomas. *Proc. Roy. Soc. A*, **201**, p. 187 (1950); ll, R. G. N., and Sayce, L. A. *Proc. Roy. Soc. A*, **215**, p. 536 52).

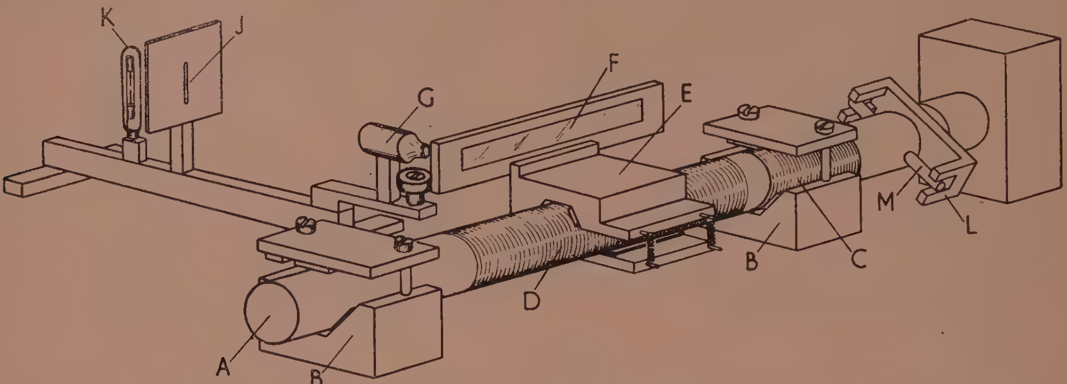


Fig. 1. Diagram showing principle of operation of dividing engine

In the foregoing arrangement, the successive images of the slit constituting the scale are separated by a distance equal to the mean pitch of the helix because the triggering switch of the flash tube is actuated by a cam once every revolution of the cylinder. In a further development of the device, a second switch is placed in series with the main triggering switch and is operated by a second cam geared to revolve in a 1 to 10 ratio to the rotation of the cylinder. This second switch keeps open the triggering circuit during nine out of every ten operations of the main triggering switch but is arranged to make contact for a short period starting just before each tenth closure of the main triggering switch. In this way a scale is produced consisting of a succession of slit images spaced at ten times the pitch of the helix but of an accuracy equal to that of the finer scale described above. In a similar way, scales may be made of any sub-multiple of the pitch of the helix by operating the second switch in the triggering circuit by a cam suitably geared to the driving mechanism of the cylinder.

For ease in reading a linear scale, it is customary for the successive lines constituting the scale to be of unequal lengths as, for instance, by lengthening every fifth or tenth line. The scales produced by the present device may be similarly constructed in the following manner: the slit which is imaged by the lens upon the photographic plate is obscured at its upper end by an electromagnetically operated shutter, which is temporarily raised just before every fifth flash and allows a slightly longer image of the slit to fall upon the photographic plate. The electromagnet lifting the shutter is energized through a switch operated by a cam suitably geared to the driving mechanism of the cylinder. Further, by suitably disposing a second electromagnet and cam-operated switch the shutter may be lifted still further at every tenth flash, so giving a still longer line at every tenth division of the scale.

DESCRIPTION OF PROTOTYPE

A model has been constructed to test the above principle. In it a 1 in. diameter brass bar bore a helix of 5000 turns per inch and upon this was mounted a Merton nut 3 in. in length bearing a photographic plate measuring 4 × 1 in. A $\frac{1}{2}$ in. focal length microscope objective was used to form upon the plate reduced images of a slit 0·001 in. in width, made by vacuum evaporation of aluminium upon a glass plate shadowed by a 0·001 in. diameter phosphor-bronze wire.

This method has been found to give extremely uniform slits if the wire is kept in intimate contact with the glass p during the evaporation. This is most easily done by f fixing the taut wire to the two ends of a thin plate (such as emulsion-free "spectrum" plate) and then keeping the p bent slightly convex to the wire.

The two bearings and the Merton nut were each lined w three strips of cork 0·03 in. in thickness, disposed at 12 intervals about the circumference of the bar and gripping by light spring pressure. These linings were initially soak in a dilute aqueous suspension of polytetrafluorethylene, obviate "stick-slip" friction, and when in use were lubricat with thin machine oil. At one of the two bearings, the bar w inscribed with a large number of shallow grooves made the steady application to it of a fine-pitched "chasing too or even of a pad of coarse emery cloth, whilst it was rotati in a lathe. Such a thrust bearing is effective only if care taken to safeguard the bar from all longitudinal stresses a it was therefore driven by the action of a fork *L*, beari upon a steel pin *M*, projecting diametrically through the e of the bar.

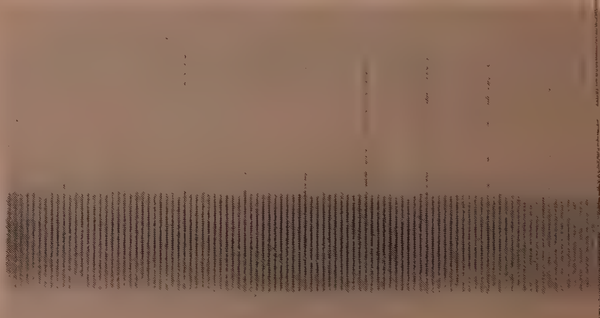


Fig. 2. Micrograph of portion of a scale of 5000 lines per inch (×150)

Fig. 2 shows a short portion of a scale of 5000 divisions inch made by this machine upon a Kodak "maximu resolution" plate.

ACKNOWLEDGEMENTS

The prototype machine described above was construc by Mr. A. E. Wales of this Laboratory to whose skill a ingenuity the author wishes to make grateful acknowled ment.

This work has been carried out as part of the resear programme of the National Physical Laboratory, and published by permission of the Director of the Laboratory

he processing and some characteristics of coaxial cylinder, corona stabilizer tubes

y A. J. L. Collinson, B.Sc., A.M.I.E.E., A.Inst.P., and D. W. Hill, M.Sc., Grad.Inst.P., Department of Electrical Engineering and Physics, Borough Polytechnic, London

[*Paper received* 2 *September*, 1954]

Suitably processed, corona, stabilizer tubes filled with pure hydrogen are shown to have a running voltage stability over 24 hours of better than 0·02% and over 1000 hours of better than 1%. The variation of slope resistance with pressure and current has been investigated and the results compared with theoretical prediction. The variation of running voltage with temperature shows small positive coefficients (approximately 0·005% per °C). Some investigations into maximum current drawn show the possibility of this being raised by suitable glow discharging.

ne use of the corona discharge between coaxial cylinders r stabilization of low-current supplies at voltages up to 00 V and more is well known and a number of papers have ppeared dealing with the construction, processing and aracteristics of corona, stabilizer tubes.(1–5)

There are several factors to be considered in the per-rmance of these tubes. It seems generally agreed that ydrogen is the most suitable filling gas and data has been ublished(5) giving variations of striking voltage for steady orona with pressure and electrode dimensions. In the orona discharge an increase in voltage across the tube leads an increase in current, whereas on transition to a glow ischarge the reverse is the case. This means that the slope esistance of a corona tube is positive and consequently a eries resistance large compared with the slope resistance ust be used for efficient stabilization. The effect of the rcuit parameters has been discussed in detail by Lichtman.(4) owever, it will be clear that the slope resistance of the tube an important factor and for a given series resistance the wer the slope resistance the better the stabilization ratio. further factor of importance is the maximum current taken y the tube before transition to glow discharge takes place. he present practice seems to be to restrict the working urrent to less than 100 μA, although there are applications here running at higher currents might be desirable.

The purpose of the present investigation was to study the haracteristics of corona tubes using pure hydrogen, the ffect of different processing schedules being observed. As ar as is known previous investigators have used tank hydrogen it was thought that experiments carried out with pure ydrogen would be of value. Measurements were also made f the variation of slope resistance with the striking voltage, ressure and current. A theoretical formula(6–8) exists elating the slope resistance with the striking voltage and other arameters and it was felt that it would be of interest to know what extent it could be relied upon for design purposes.

TUBE CONSTRUCTION

The electrode systems of most of the tubes used in this nvestigation consisted of a nickel tube 3 cm long, 7 mm dia-eter with an anode of 0·8 mm diameter of centreless round tungsten rod, the latter being held accurately con-entric with the nickel tube by means of ceramic spacers. ome tubes were made with glass bridges holding the centre ire in position so that the tube interior could be observed. lso, a few tubes were used with cathodes twice as long and ome with cathode diameters doubled.

APPARATUS AND METHODS

For filling the tubes with pure hydrogen a conventional acuum system using a mercury vapour diffusion pump was sed with a heated palladium tube for admitting the hydrogen. The pressure of the admitted gas was measured with a mercury manometer and, in addition, a differential oil manometer was installed to measure small differences in pressure. Every precaution was taken to exclude mercury from the system by the use of liquid air traps. The tubes and manifold could be baked up to 450° C and an eddy current heater was used to heat the cathodes up to 700–800° C.

For measurement of starting and running voltages, two separate variable power supplies were used: one, which was unstabilized, was used to supply the tube current; the other, which was accurately stabilized, was balanced against the first using a microammeter and its voltage was measured by means of a potentiometer by Cambridge Instrument Co. Ltd. By this means small changes of voltage of the order of 0·01% could be detected and measured.

It was found far more convenient to measure the slope resistance by an alternating current bridge method than from current voltage characteristics and a suitable bridge was developed for this purpose. The sensitivity varied a little over the range of slope resistance measured but, in general, over the whole range an accuracy of at least 2% was obtained.

PROCESSING AND RUNNING LIFE

For the first tubes filled a simple processing schedule was used; the tubes were evacuated to 10^{-5} mm of mercury and baked for an hour at 450° C, eddy current heating for some minutes being carried out before and after baking. For tubes which had been exposed to air an additional baking in hydrogen was carried out. It is interesting to note that on first filling a tube the striking voltage varied very little with time, whereas the slope resistance could vary as much as 50% either way until it settled down. This was attributed to the fact that very small amounts of impurity can affect the slope resistance considerably without having much effect on striking voltage. If pure hydrogen was used and the system thoroughly outgassed, the slope resistance remained fairly constant from the first. Tubes which were processed in this manner were sealed off, left to settle down and then run steadily at 100 μA; slope resistance and running voltage being measured at intervals. Running voltage as opposed to striking voltage was measured because the latter measurement could not be repeated to better than 1%. Fig. 1 shows the result of a typical tube where it will be seen that the running voltage fell off with time, a large decrease (3%) being observed in the first 30 hours of running. Thereafter, the curve flattens out with increasing life, such tubes holding 0·1% over 24–30 hours. The reduction in running voltage was accompanied by a small drop in slope resistance and as the running voltage became constant so did the slope resistance. If during the run a tube was rested a small increase (approximately 0·2–0·5%) in running voltage was found on re-starting, but the tube recovered fairly rapidly.

The possible cause of these changes is that the continuous discharge is giving rise to an adsorbed hydrogen layer on the cathode which brings about a small change in pressure and a difference in cathode work function which alters the striking voltage and slope resistance. If this were so it would be expected that subjecting the cathode to a more violent bombardment, i.e. by a glow discharge, would age the tube more rapidly. Accordingly, a glow discharge of 30 mA at 400 V and a pressure of hydrogen at 0·5 cm of mercury was passed for 2 hours. The tube was then evacuated and refilled with hydrogen without any other process being carried out. It was found that this greatly reduced the time for the tube to be aged, the running voltage now falling off by 0·1 to 0·2% in 6 hours, the subsequent fall being very small, it being possible to produce tubes whose running voltage will remain constant to 0·02% for over 24 hours. In addition, such tubes on standing show an almost negligible increase in running voltage.

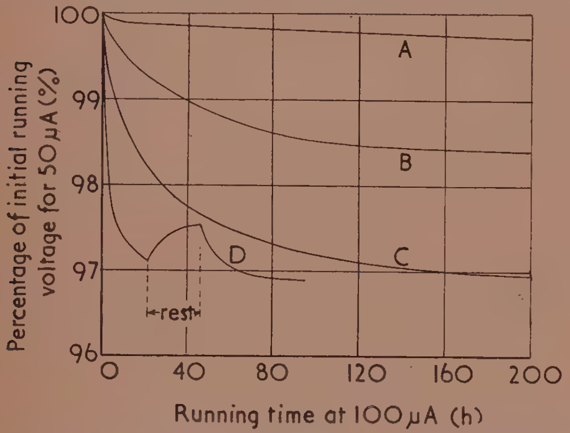


Fig. 1. The effect of running life on running voltage

Curve *A*, after glow discharge treatment; Curve *B*, after glow discharge followed by baking in hydrogen; Curves *C* and *D*, after simple processing.

The simple passing of a glow discharge was by far the most effective treatment. Baking in hydrogen is not effective and baking in hydrogen after the glow discharge to some extent undoes the glow discharge effect as is shown in Fig. 1.

It thus seems fairly certain that the effect of the glow discharge is to accelerate the process of hydrogen adsorption by the cathode and allow it to reach equilibrium more rapidly. In addition, the glow discharge possibly causes a clean-up of the thin oxide film on the cathode. That such oxide films are very tenacious and can only be removed by positive ion bombardment has been shown by Llewellyn-Jones and Davies.$^{(9)}$ The effect of the glow discharge on the cathode is shown by the following procedure. A glow discharge of 20 mA was passed and at definite time intervals the tube was evacuated and refilled with hydrogen. The striking voltage was determined for a small range of pressures around 2 cm of mercury pressure. In this way a graph was plotted of striking voltage at 2 cm of mercury against hours of glow discharge. The curve obtained is shown in Fig. 2 and it will be seen that the striking voltage becomes constant after 3 hours.

It is emphasized that care must be exercised in the use of the glow discharge. If the discharge is made too violent or passed for too long a time there is a possibility of the maximum tube current being considerably reduced, particularly for tubes filled to higher pressures, i.e. corresponding to running voltage of 800 V or more. This may be due to sputtering inside the tube causing roughness and thus allowi a point discharge to develop. Also, the ceramic spacer mu be made so that the sputtered metal falling on it does n give rise to a conducting path from anode to cathode.

A tube which has been processed by glow discharge above was run at 100 μA for 1000 hours, the slope resistan and running voltage being taken every 24 hours. Durin this time the slope resistance did not vary (within the limi imposed by measurement), but there was a steady fall (running voltage mounting to approximately 0·016% per da the total percentage fall in the period 50–950 hours bein 0·64%. This residual fall in running voltage is possibly du to a slow absorption of hydrogen in the cathode leading to hardening of the tube. Possible hardening due to adsorptio in the glass walls seems ruled out as the fall in voltage on takes place while the tube is running and there is almost zer change during rest periods.

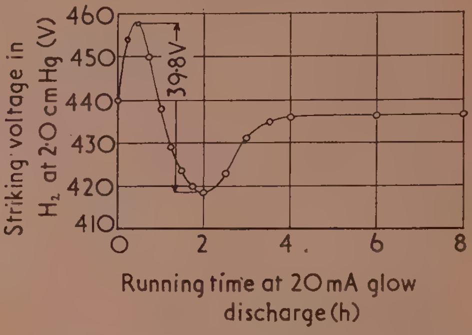


Fig. 2. The effect of a heavy glow discharge on the striking voltage

TUBE SLOPE RESISTANCE

A set of resistance measurements was made in order t show the variation of slope resistance with pressure an current. The corona tube bodies were processed by bakin and eddy current heating and filled with gas to a pressu of a few millimetres of mercury. Measurements of strikin voltage and resistance were taken, the pressure being increase by a few millimetres of mercury after each set of readings. Th striking voltage for steady corona was taken as that voltag at which separate Geiger pulses seen on the oscillosco changed abruptly to a continuous grass-like trace. The result are shown in Fig. 3, the values being taken from the Pasche minimum at 320 V up to 1500 V.

A theoretical expression relating tube voltage *V*, strikin voltage V_s, pressure *p*, tube dimensions and current wa first obtained by Townsend$^{(6)}$ and modified versions wer produced by Werner$^{(7)}$ and Loeb.$^{(8)}$ The formula is derive on the assumption that the ionization takes place in a regio close to the wire of radius r_u, the remainder of the tube bein filled with positive ion space charge. It is assumed that th field close to the wire remains constant so that when th tube voltage is increased the space charge (and the curren increase accordingly, maintaining the field at the wire at it original value.

The full expression is:

$$V(V - V_s) = \frac{ip \log (A/a)}{2K_0}\left[(A^2 - a^2) - (r_u^2 - a^2)\frac{\log (A/a)}{\log (r_u/a)}\right] \qquad \text{(1}$$

where *A* and *a* are the radii of cathode and anode respectivel K_0 is the mobility at a pressure of 1 mm of mercury; *i* is th urrent per unit length of the tube. At higher pressures the egative term in the bracket is small giving

$$V(V - V_s) = \frac{ipA^2 \log (A/a)}{2K_0} \qquad (2)$$

n expression originally obtained by Townsend.(6)

Differentiating equation (1) gives the slope resistance per nit length of the tube.

$$R_c = \frac{\log (A/a)}{2K_0(2V - V_s)}\left[(A^2 - a^2) - (r_u^2 - a^2)\frac{\log (A/a)}{\log (r_u/a)}\right] \qquad (3)$$

$_u$ will vary with pressure, but it can be determined if it is ssumed that r_u is situated a number n electron free paths rom the wire, n being independent of pressure. When the alue of R_c falls to zero, r_u should equal the cathode radius,

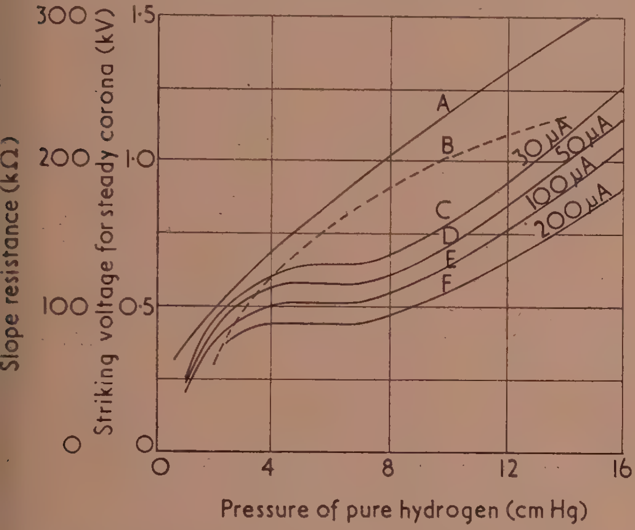


Fig. 3. Variation of slope resistance with pressure

Tube dimensions: cathode diameter 6·9 mm, anode diameter 0·78 mm, cathode length 3·6 cm.

Curve *A*, striking voltage against pressure; Curve *B*, slope resistance (theoretical) against pressure; Curves *C* to *F*, slope resistance (experimental) against pressure.

ence by extrapolating the curves at higher pressures back to common point the pressure for which $r_u = A$ can be etermined. This pressure was found to be 1·1 cm of ercury giving $n = 60$. r_u then varies from 0·231 cm at $= 2$ cm of mercury to 0·066 cm at $p = 14$ cm of mercury, being equal to 0·078 cm.

At low pressures, when r_u is rather larger than a, the quation should fail; but at higher pressures better agreement night be expected although this would only be approximate s guard rings are not fitted to the corona tubes. It will be een that the theoretical curve only approached the experimental one for higher pressures and low currents. In addition, he very large variation of slope resistance with current for a onstant pressure is not predicted by theory, for, apart from he change due to the very small variation of $2V - V_s$ with urrent, the slope resistance should remain constant. This shown in Fig. 4 in which resistance against current is lotted for two tubes, one twice as long as the other. The arge deviation from the theoretical curve cannot be explained y end effect since the two curves are the same form.

These large deviations from theory are surprising as it is tated in the literature that equation (2) holds approximately over large ranges of potential.(10) A probable reason is that, in deriving the theoretical expression, it is assumed the space charge does not greatly change the field in the body of the tube.(8) This effectively means that the quantity $2iA^2/a^2K_0X_a$ is assumed to be small compared with unity. (X_a is the field at the anode.) With the tubes used in this investigation, the value of this quantity is only small compared with unity if the current is very small. For instance, for the tube used in obtaining the curves in Fig. 3 at 500 V, $2iA^2/a^2K_0X_a$ is 0·058 at a current of 1 μA. Hence it would be expected that departures from the theoretical voltage-current curve would be seen at a few microamperes. This can be seen in Fig. 5 where the curve for a 560 V tube is plotted at small currents.

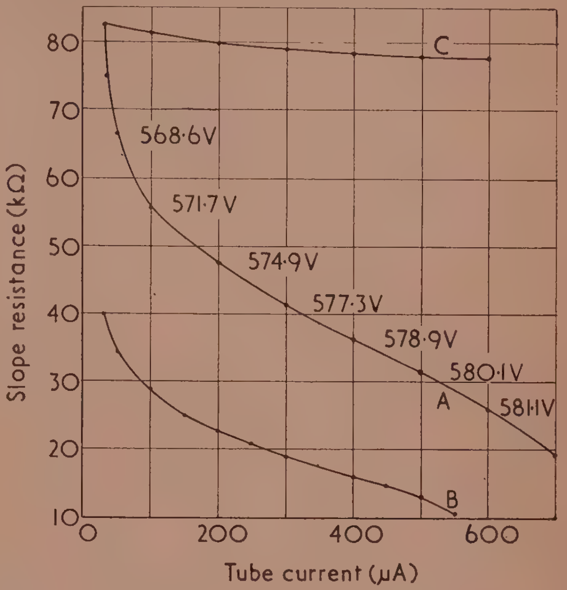


Fig. 4. Slope resistance against current for constant pressure

Curve *A*, cathode length 3·8 cm; Curve *B*, cathode length 7·6 cm; Curve *C*, calculated theoretical curve $R \propto 1/(2V - V_s)$.

Thus, as far as the design of corona tubes is concerned, the Townsend formula can only predict characteristics approxi-

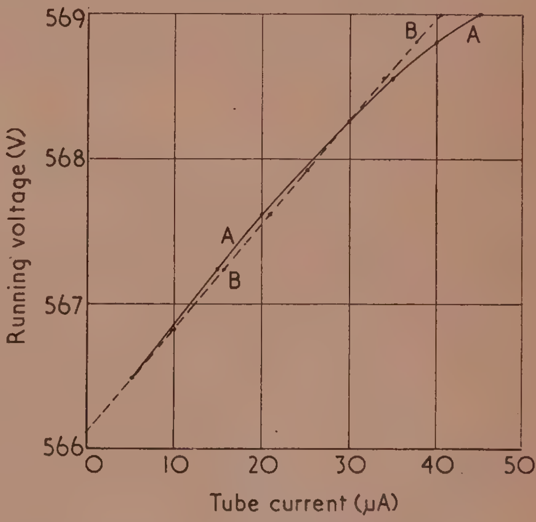


Fig. 5. Running voltage curve against current

Curve *A*, experimental curve; Curve *B*, theoretical curve $V(V - V_s) \propto i$.

mately and then only for currents of the order of a few microamperes or less.

EFFECTS OF AMBIENT TEMPERATURE

For the measurement of temperature effects a small hot air oven was used, its temperature being automatically controlled to ±0·25° C. The results for a typical tube are shown in Fig. 6 where running voltages at fixed current against temperature are recorded. It will be seen that the changes are quite small, of the order of 0·005% per °C, the total change for nearly 100° C being only of the order of a few volts. If the density of the gas remains constant, the change in running voltage should be due to a change in mobility of the positive ions which according to theory varies approximately inversely as the absolute temperature. However, the predicted rise in $(V - V_s)$ with temperature due to this cause using equation (2) is much smaller than that actually obtained in practice. Consequently it is assumed that the majority of the changes are due to small changes in density brought about by gas being emitted from the walls.

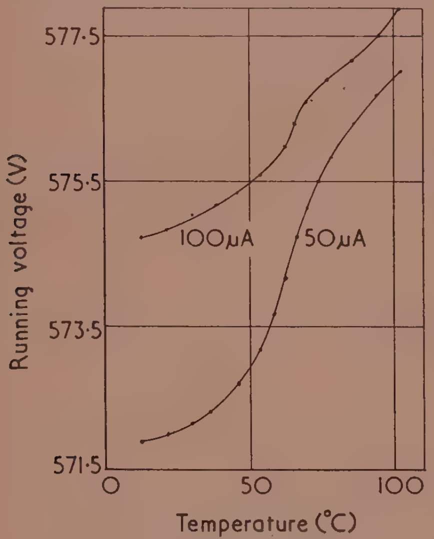


Fig. 6. Effect of temperature on tube running voltage

Out of a number of tubes investigated, in no case was a negative temperature coefficient found as was reported by Benson and Smith.(11) If the tube condition is suitable, such effects could be due to the fall in running voltage occurring as the tube is run.

CORONA RANGE

The corona regime is limited to a definite current and corresponding voltage range. The minimum current is determined by the transition from Geiger discharge to continuous corona and the maximum current by the transition from corona to glow discharge. As far as the former is concerned it was found that the minimum current was approximately 1 μA for 6 mm diameter tubes and 4 μA for 12 mm tubes. Small amounts of impurity such as oxygen resulted in larger Geiger pulses and raised the minimum current.

With regard to the transition to glow discharge, this is marked by an abrupt change from positive to negative slope resistance giving rise to relaxational oscillations if the power supply provides an appropriate shunt impedance. For tubes of the same dimensions, filled with pure hydrogen and processed similarly, the maximum current was approximately the same for the same gas pressure. However, there ar circumstances in which the maximum current is considerabl reduced and, as pointed out by Lichtman,(4) inaccurat centring of the anode wire will cause this. Also, it wa found that the cathode of a tube could become conditioned b excessive or localized glow discharging, such effects bein permanent and not always curable by reprocessing. In on case such a tube only became normal on allowing the cathod to become oxidized but reverted to its original state when th oxide layer was removed.

The tendency for a tube to go prematurely into glow dis charge can to some extent be prevented by putting larg resistances in series and condensers of suitable capacity i parallel with the tube. Lichtman(4) has given calculation for obtaining appropriate values. It is felt, however, tha such shifts are unnecessary and it was found that if a tub was correctly made, filled with pure gas and suitably pro cessed, it would exhibit stable corona over the whole of it range with a series resistor of only a few thousand ohms.

The variation of corona range with pressure is shown i Fig. 7, where it is seen that the maximum current draw initially falls with increase in pressure but increases steadil thereafter. As the current is increased, the field at the wir remains constant and the density of the space charge increase resulting in an increase in the field in the body of the tube

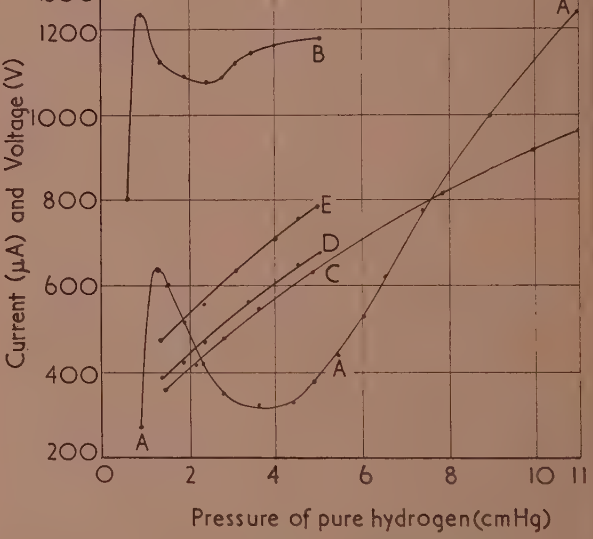


Fig. 7. Variation of corona range with pressure

Curve *A*, maximum current against pressure; Curve *B*, as Curve *A* after glow discharge treatment; Curve *C*, striking voltage against pressure; Curve *D*, as Curve *C* after glow discharge treatment; Curve *E*, running voltage for maximum corona current against pressure after glow discharge treatment.

As has been shown by Huxley and Bruce,(12) provided tha the positive space charge almost fills the tube, the field ulti mately becomes nearly uniform and the transition from corona to glow discharge takes place when the potentia difference across the tube is about equal to the sparkin potential for parallel plate electrodes, placed a distance apar equal to the difference between cathode and wire radii. A steady increase in maximum current with pressure woul therefore be expected. That the reverse occurs at lowe pressures is due to the fact that at these pressures the spac charge only partially fills the tube, so that a larger current ca be taken before the field rises at the cathode to the figur necessary to give rise to the transition.

If the above reasoning is correct, then it would be expected iat the state of the cathode would have an effect on the orona range. This was found to be so and in Fig. 7 the orona range is plotted (at low pressures) for the same tube fter glow discharge at 20 mA had been passed for 3 hours t a pressure of 0·5 cm of mercury. It will be seen that hereas the starting voltage is increased only slightly the orona range is considerably increased. This is not surprising s it is known that the state of a cathode can have a coniderable influence on the sparking potential for parallel late electrodes.(9) A further point is that whereas the iaximum current passes through a minimum with increase i pressure, the potential required to produce that current icreases steadily in the usual manner of a Paschen curve.

Some experiments were also carried out with tubes of iameter twice that of the tube used for Fig. 7. It was found iat, in general, the corona range was increased, the minimum i the curve being shifted towards lower pressures. It was ound that increasing the length of the tube did not alter the orm of the curve, the maximum current merely being increased roportionally as the length of the tube. Although the results n corona range can only be regarded as preliminary, partiularly as regards the effect of glow discharging, it is clear that or tubes working in the voltage range 400–1500 V currents f the order of 1 mA can be drawn. For cathodes a few entimetres long and diameter of 6 mm the slope resistance t such currents would be less than 10 000 Ω.

ACKNOWLEDGEMENTS

The authors wish to thank Mr. J. P. Wolfenden in whose epartment the work was carried out: also, those colleagues who assisted from time to time and, in particular, Mr. C. W. Cook for invaluable help.

REFERENCES

(1) Medicus, G. *Z. Tech. Phys.*, **14**, p. 304 (1933).
(2) Blifford, I. H., Arnold, R. G., and Friedman, H. Report N.3140, U.S. Navy Research Laboratory, Washington.
(3) Jacques, W. Memo. EL/M/42. Atomic Energy Research Establishment, Harwell.
(4) Lichtman, S. W. *Proc. Inst. Radio Engrs*, **39**, p. 419 (1951).
(5) Shelton, E. E., and Wade, F. *Electronic Engng*, **25**, p. 18 (1953).
(6) Townsend, J. S. *Phil. Mag.*, **28**, p. 83 (1914).
(7) Werner, S. *Z. Phys.*, **90**, p. 356 (1934); **92**, p. 705 (1934).
(8) Loeb, L. B. *Fundamental Processes of Electrical Discharge in Gases*, p. 486 (New York: John Wiley and Sons, Inc., 1939).
(9) Llewellyn Jones, F., and Davies, D. E. *Proc. Phys. Soc.* [*London*] *B*, **64**, p. 397 (1951); **64**, p. 519 (1951).
(10) Loeb, L. B. *Phys. Rev.*, **90**, p. 144 (1953).
(11) Benson, F. A., and Smith, J. P. *J. Sci. Instrum.*, **30**, p. 192 (1953).
(12) Huxley, L. G. H., and Bruce, J. H. *Phil. Mag.*, **23**, p. 1096 (1937).

A measuring apparatus employing a reference line of variable brightness

By C. S. Lees, B.A., Ph.D., A.Inst.P., Atomic Energy Research Establishment, Harwell, Berks.

[*Paper received* 17 *September*, 1954]

An improvement on the normal travelling microscope arrangement is described, for measurement of electron or X-ray diffraction films. The new apparatus uses as a reference line the image of an illuminated glass fibre of adjustable brightness.

he measurement of photographic plates is necessary in a ide range of scientific work, and the travelling microscope normally used for this purpose. The optical system used orms an image of the photographic plate, suitably illuminated, nd in the plane of this image is a cross wire which is brought ito coincidence with the line or other feature of the photoraph which has to be measured. Weak lines cannot be ieasured accurately because the black cross wire obliterates iem.

The apparatus to be described avoids this difficulty by mploying as reference line the image of an illuminated glass bre of adjustable brightness. The brightness is adjusted so iat the reference line is just visible as a line of greater illuination compared with the relatively dark line which is eing measured. The advantage of this arrangement is that ie contrast between the reference line and the line to be ieasured is only just sufficient to make it visible, and even ery weak lines can therefore still be seen and measured ccurately.

DESCRIPTION OF THE APPARATUS

The new arrangement has been used for measuring electron ffraction photographs and X-ray diffraction films. The details given refer to an apparatus designed for the former. Fig. 1 shows the apparatus diagrammatically. The photo-

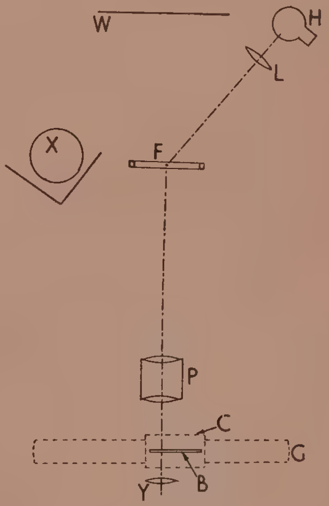


Fig. 1. Diagram of optical system

graphic plate *B* to be measured is mounted on the carriage *C* of a normal screw travelling microscope in the place normally occupied by the microscope, and is traversable along the guides indicated by *G*. The glass fibre *F* is mounted under slight tension in a 3 in. diameter brass ring, its length being perpendicular to the plane of the diagram. It is illuminated obliquely, at about 40°, by the headlamp bulb *H* and the lens *L*. An image of this glass fibre, reduced in size in the ratio 3 : 1, is formed by the wide aperture (*f*/1·9) projection lens *P*, and it is this image which is used as the fixed reference line. General illumination of the photographic plate is provided by a white screen *W*, illuminated by a lamp *X*, which is of course shielded from the direct view of the observer. The plate is viewed through an ordinary magnifying lens *Y*. The details of the actual apparatus are shown in the drawing of Fig. 2. The following features may be noted.

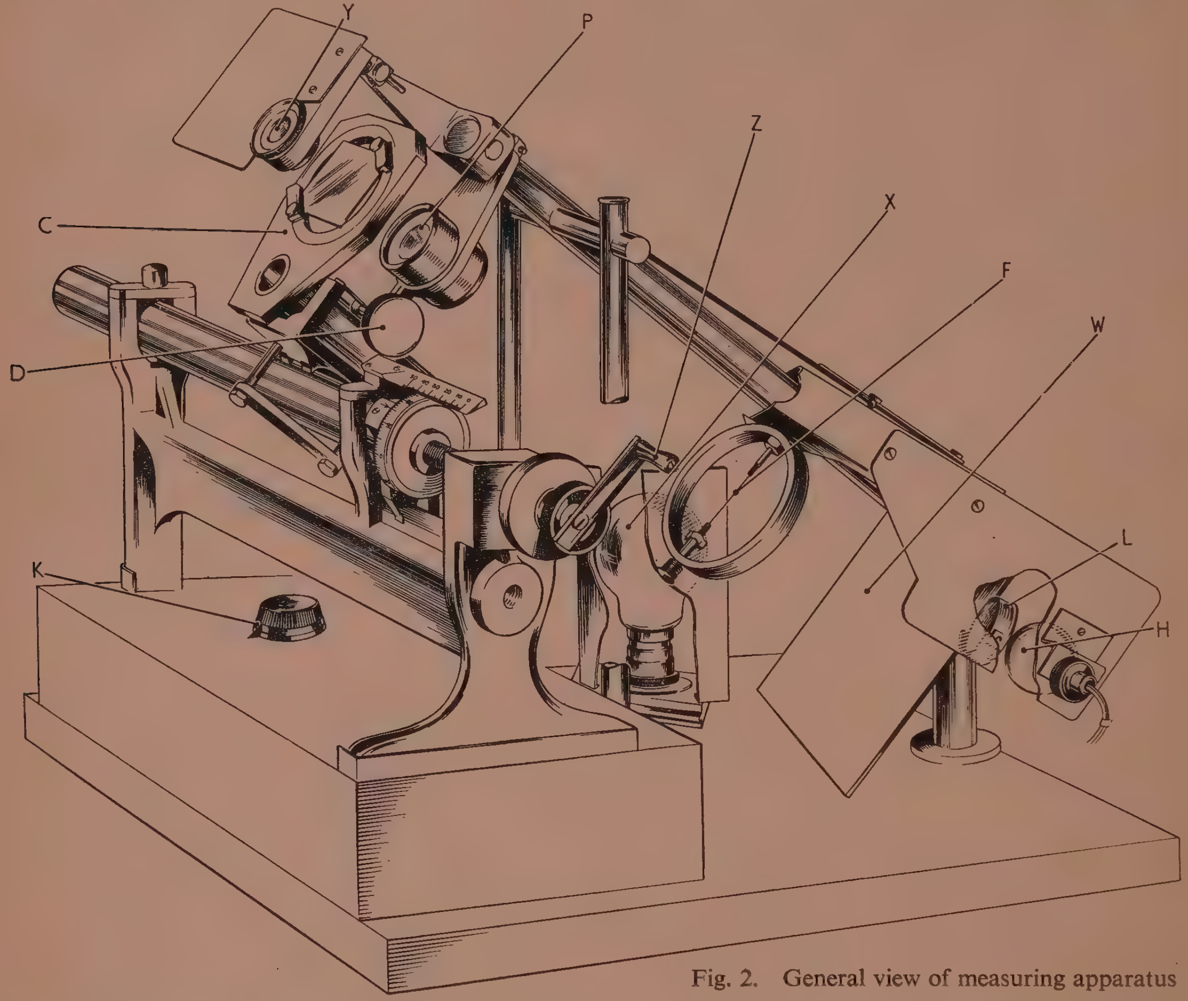


Fig. 2. General view of measuring apparatus

(1) The photographic plate holder *C* can be moved parallel to the axis of the optical system by means of the knob *D*, which operates an ordinary rack and pinion focusing movement. This enables the photographic emulsion to be brought into coincidence with the reference line image. For convenience in reading, the axis of the optical system slopes at about 30° to the horizontal.

The handle *Z* on the right-hand side of the apparatus operates the traversing screw.

(2) The illuminated glass fibre *F* is kept under slight tension by a very light spring at its lower end. The mounting of the lamp *H* and lens *L* has been cut away in Fig. 2 to show these two components. The filament of lamp *H* is placed parallel to the glass fibre *F*, and lens *L* throws an image of the filament some distance beyond *F*; the image must not be too close to *F* or the illumination would be uneven. The brightness of the reference line is adjusted by means of a knob *K*, which operates a rheostat in the circuit of lamp *H*.

(3) The glass fibre is 20–30 μ in diameter. The width o its image is considerably less than the 10 μ or so given by the magnification ratio of 3 : 1, since only a narrow strip of the glass fibre will refract the incident light in the direction of lens *P*.

(4) Since the image of the glass fibre is formed by a wide aperture lens, there is a considerable range of position for the eye of the viewer, and this has a marked effec in diminishing eye-strain. The viewing lens *Y* can easily be changed to provide the most suitable magnification for electron diffraction rings of good resolution, a magnification of ×12 is suitable, and readings are then taken to 0·001 mm. For measuring broader rings, a lens *Y* of less power is best.

ACKNOWLEDGEMENT

I am indebted to Mr. J. V. Hicks for the construction of the apparatus.

combined strain and curvature gauge for use in testing concrete beams

By J. M. PRENTIS, M.Sc.(Eng.), University of Aberdeen

[*Paper first received* 13 *August, and in final form* 9 *September*, 1954]

An instrument is described for determining the distribution of bending strains in a concrete beam. It is claimed that the gauge enables the sought information to be gained at the expense of less labour than is required by use of conventional methods. The instrument is fixed to the beam for the duration of the test. Being robust and inexpensive in construction it need not be removed when failure of the specimen is imminent.

e following data are frequently required from bending ts on concrete beams; (*a*) the strains in the concrete, and the position of the neutral axis.

The usual method of obtaining this information is to point a number of strain gauge stations on the side of the am (Fig. 1), readings from which enable the strains to be otted (Fig. 2). The strains e_c and e_t, and the depth of the utral axis *nd*, are obtained from this graph, *d* being the pth of the beam.

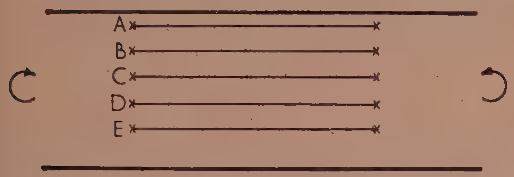


Fig. 1. Normal layout of strain gauge stations

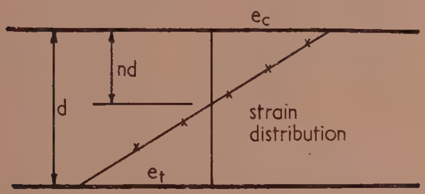


Fig. 2. Distribution of concrete strains

If it is necessary to take readings right up to the moment failure, then it is usual to use either electrical resistance ain gauges or a demountable mechanical gauge. The rmer are considered by many to be unsatisfactory for use n concrete so that the latter finds more general favour. ne demountable gauge is less accurate than the fixed gauge it it has two advantages. Firstly, owing to space considerations it is possible to have more gauge stations for a given depth of beam; in testing a small beam it may be desirable to have a vertical spacing of as little as $\frac{1}{4}$ in. Secondly, the demountable gauge can be used to take readings until the beam fails whereas normally it is prudent to remove any fixed mechanical gauges as collapse becomes imminent in order to prevent damage. This makes it impossible to take further readings at a crucial stage in the test.

Whatever the instrument employed, the general method has one drawback. At any given load stage it is necessary to take a large number of readings, say ten or more gauge stations on both sides of the beam, book them, reduce them and then plot a graph in order to obtain e_c, e_t and *nd*. The large number of gauge stations are used to assist in selecting the best straight line to represent the strain readings, which generally suffer from a certain amount of scatter. They are also needed because generally those in the lower part of the beam become unreliable as tension cracks intervene. This means that it is essential to have at least three stations operative in the compression zone in order to fix with certainty the position of the neutral axis.

The instrument described below was designed to eliminate this difficulty by measuring only one strain and the radius of curvature. It is then simple to obtain e_c, e_t and *nd* by calculation. As only two readings are taken it is essential that they be reliable. This suggests that some sort of fixed gauge be used. If, however, it is to be left in position whilst the beam fails it must be strong and so simple and cheap in construction that any part which should be damaged could easily be replaced.

CONSTRUCTION

Fig. 3 shows such a gauge. Two metal blocks are fixed to the top of the beam by means of small fixing bolts or pieces

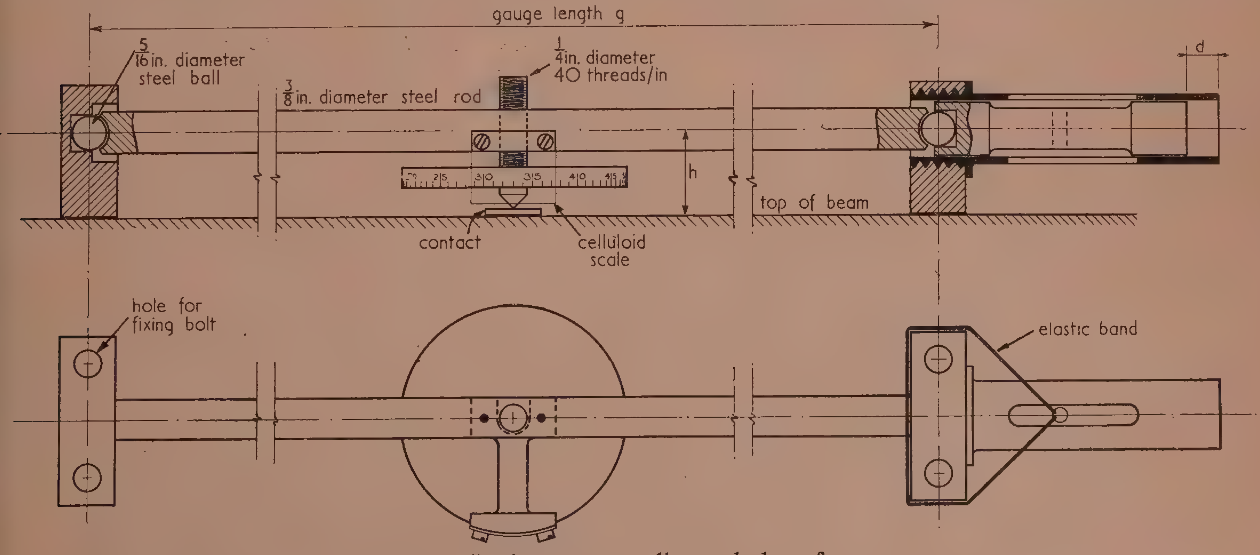


Fig. 3. Section on centre line and plan of gauge

of wire cast therein. The left-hand block has a steel ball fitted into a recess as shown. The metal of the block is pinched round the ball to retain it there permanently. The right-hand block carries a metal tube wherein slides a piston which has a steel ball in the centre of one end and is flat at the other. The piston is spring loaded by means of an elastic band and the steel rod is held in position by virtue of its cupped ends. As its centre the rod carries a screw gauge using a standard micrometer screw thread of forty turns per inch. Lines scribed on the celluloid scale enable both the full and partial revolutions to be counted. The end of the screw is pointed and the instant of contact with a metal plate stuck on top of the beam is indicated by the completion of a battery and bulb circuit. The rod is prevented from rotating about its axis by means of a U-shaped perspex guide glued to the contact plate, Fig. 4. The U-shape enables the rod to be completely removed without detaching the fixed blocks.

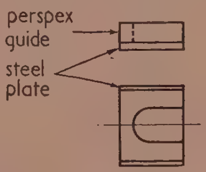


Fig. 4. Guide to locate point of contact

As the beam is strained the piston moves in the tube and changes in d need to be measured by means of a dial gauge adapted for this purpose. A standard 0·0001 in. gauge is used with a sleeve fitted on to the stem as shown in Fig. 5. The spigot locates the gauge spindle on the centre of the piston and the gauge is held in position by hand whilst the reading is taken. Thus the dial gauge, which is the only delicate part of the whole instrument, is protected from damage as it is removed after each reading has been taken.

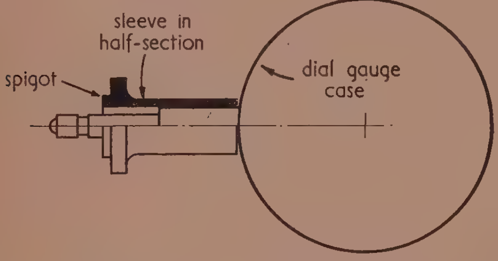


Fig. 5. Standard dial gauge with sleeve attachment

The rest of the apparatus is sufficiently robust to withstand any shocks likely to be imposed on it during the breaking of a specimen. In the event of severe crushing of the top surface of the beam the steel rod would simply push the piston right through its tube.

REDUCTION OF READINGS

As the beam is bent, its top surface curves away from the steel rod. The curvature is determined by means of the screw gauge. At the same time the plunger moves changing d by an amount X. This is shown in Fig. 6 where the curvature is exaggerated considerably.

The change of reading Δ, recorded by the screw gauge, is small compared with the other terms involved so that,

$$R - (nd + h) \simeq g^2/8\Delta$$

or more approximately

$$R \simeq g^2/8\Delta \qquad (1)$$

Again since R is large

$$[R - (nd + h)]/R \simeq (g - X)/g$$

giving

$$nd \simeq XR/g - h \qquad ($$

The strain in the top surface of the beam is given by

$$e_c = nd/R \qquad ($$

and that in the bottom surface by

$$e_t = (d - nd)/R \qquad (4$$

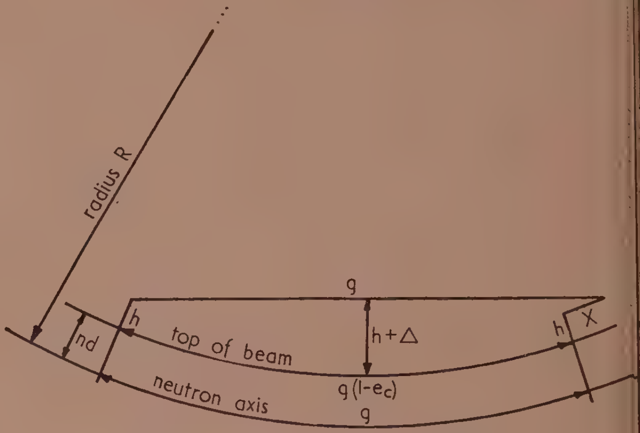


Fig. 6. Geometry of the system

CONCLUSIONS

The author has tested a number of beams to destructior using this gauge with satisfactory results. The accurac obtained depends upon the gauge length which is fixe according to the requirements of the test. The gauge lengt used by the author is 12 in. The disk of the screw gauge i marked round its edge at 5° intervals, i.e. seventy-two division per revolution at a spacing of approximately 0·1 in. It i possible to estimate to a fifth of a division and readings are repeatable to this accuracy. Thus Δ is measured accurate tc $\pm 0{\cdot}1/(72 \times 40) = 0{\cdot}000035$ in. X is measured directly by the 0·0001 in. dial gauge and it is found that readings are repeatable to one half division, though recorded only to the nearest division. Since the top surface of a concrete beam is rarely smooth h should be measured when the gauge is in position at a number of positions and the average taken. In this way the average h is accurate to $\pm 0{\cdot}01$ in. and in the author's gauge is approximately 0·8 in.

It follows from equations (1), (2) and (3) that

$$e_c = X/g - 8h\Delta/g^2$$

Thus the possible error in e_c due to δX, $\delta\Delta$, and δh is

$$\delta e_c = \delta X/g - 8h.\delta\Delta/g^2 - 8\Delta.\delta h/g^2$$

Assuming that the errors accumulate

$$\delta e_c = \pm (0{\cdot}00005/12 + 8 \times 0{\cdot}8 \times 0{\cdot}000035/144 + 8\Delta \times 0{\cdot}01/144$$
$$= \pm (4{\cdot}2 + 1{\cdot}6 + 560\Delta) \times 10^{-6}$$

The first two components of this error correspond to a stress of about 25 lb/in.^{2}, which is negligible. The last component, $560\,\Delta \times 10^{-6}$, is due to the possible error in h Now $e_c = nd/R = 8nd\Delta/g^2$ so that the percentage error du to this component is $1/nd$. That is to say if the neutra axis is two inches below the top surface of the beam the erro in e_c is $\frac{1}{2}$%.

The limits for repeatability of readings have already been ommented upon. The author has to date tested nine beams sing this gauge. Although all the tests were carried out peedily the number of readings which have had to be repeated s clearly being in error is very small. Likewise there is ery little evidence of scatter in the plotted results.

ACKNOWLEDGEMENTS

The gauge described was made in the workshop of the Department of Engineering at Aberdeen University. The author wishes to express his thanks to Professor J. Allen for granting the facilities and encouraging the research of which the construction of the gauge was part.

An apparatus giving an α-particle microbeam for the irradiation of living cells

By H. A. B. Simons, M.A., Ph.D., Department of Physics, Royal Free Hospital School of Medicine, University of London

[*Paper first received* 30 *July, and in final form* 20 *September*, 1954]

A microscope fitted for phase contrast observation is modified so that a biological specimen in the centre of the field of view may be irradiated with α-particles. A beam of α-particles is obtained from a polonium source by a glass capillary collimating tube of 15 μ internal diameter, the source and collimator being mounted in a tube passing axially through the optical condenser. The irradiation rate is of the order of 1 particle/min and 70% of the particles lie within a circle of 30 μ diameter in the focal plane of the objective.

A statistical method is used to calculate the probability of irradiation of a target of known size which is irradiated for a known time.

he irradiation of a selected part of a living cell with ionizing idiation is of interest in the field of radiobiology in investiation of the mode action of such radiation.(1) An example f the action of such radiation on the nucleus of a dividing ell is the production of structural damage of the chromoomes. Lea(2) postulated the existence of a target in the cell hich must be traversed by an ionizing particle to give rise the observable effects in the cell. The apparatus described elow has been designed for use in experiments made to radiate different parts of a dividing cell with α-particles ith the object of investigating the differential effect of such radiation.

Zirkle and Bloom(3) have described a microbeam apparatus r the irradiation of living cells with a proton microbeam btained from a Van de Graaf generator. In their method a ll is selected by prior microscopic observation and then ansferred to the irradiating system. Following irradiation is transferred back to the observation microscope. In the paratus described here, the bombarding α-particle microeam is carried by the condenser of a microscope so that the radiated cell may, if desired, be selected, irradiated, and bsequently observed with the same microscope.

DESCRIPTION OF APPARATUS

Fig. 1 shows diagrammatically the arrangement of the paratus. A type M.2000 microscope by Cooke, Troughton d Simms Ltd. is fitted with a long working distance conenser, substage phase plate and phase objective. The ndenser is drilled with an axial hole $\frac{3}{16}$ in. diameter into hich is fitted a brass sleeve carrying the α-particle source d collimating system. The α-particles emerge from the p of the collimator tube assembly and move vertically wards to strike the specimen which is on the under side the moist cell carried on the stage of the microscope.

Irradiation is carried out by racking the condenser vertically wards until the top of the collimator assembly is within proximately 0·2 mm of the underside of the coverslip closing the moist cell. Under these conditions the αrticle beam is aligned so that the centre of the beam coincides th the centre of the field of view of the objective. In g. 1, the objective is shown raised from the coverslip of the oist cell, but in use a 1·8 mm oil immersion objective is ed on to the top of the cell.

Particles emerge from the collimator at a rate of the order of 1 particle/min, but the moment of emergence of each particle is not known or the exact position where it strikes the irradiated specimen. Thus, as shown later, a statistical method may be used to calculate the probability of hitting a target of known size irradiated for a known time.

The specimen on the stage cannot be clearly observed during irradiation since the condenser must be raised from its normal working position, but after sufficient time has elapsed to allow for irradiation, the condenser may be lowered to its normal position and observation continued. A circular brass stop $\frac{1}{8}$ in. in diameter is soldered to the end of a horizontal brass wire which may be rotated about an axis passing vertically through the stage. This stop is rotated into place over the end of the collimator when the irradiation is finished.

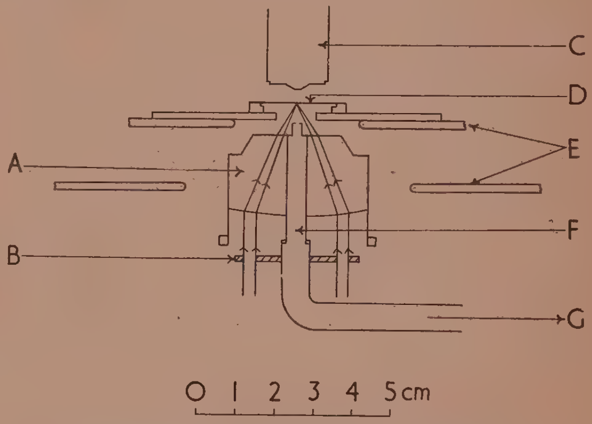


Fig. 1. General diagram of apparatus

A, condenser; *B*, substage phase plate; *C*, objective; *D*, moist cell; *E*, stage; *F*, collimator tube assembly; *G*, vacuum line.

COLLIMATING SYSTEM

Fig. 2 shows the arrangement of the radioactive source and the collimator inside the brass sleeve which is inserted into the optical condenser. The upper end of the sleeve is reduced in diameter to $\frac{3}{32}$ in. and projects $\frac{1}{8}$ in. above the surface of the condenser so that it may be inserted through the hole in the bottom of the moist cell shown on the stage of the microscope in Fig. 1.

Inside the sleeve are pushed two brass cylinders, *A* and *B*, carrying respectively a glass capillary tube and the radioactive source. Each cylinder has a saw-cut down the curved surface, which is not shown in the diagram, to prevent trapping of air by the cylinders when inserted in the sleeve.

The cylinder *A* is drilled with an axial hole approximately 0·5 mm in diameter so that the glass capillary tube held in it is a sliding fit. The collimating capillary tube is made of Pyrex glass and experiments have been made with a range of tubes of differing internal diameters. The collimating tube now in use is 5 mm long with an external diameter of 0·5 mm and an internal hole of 15 μ diameter. Tubing which is straight over this length may best be prepared by a method given by Templeton.(4) A glass capillary tube of say 5 mm external diameter is electrically heated by a spiral of chromel wire wound round but not in contact with it. The tubing is extended when soft by a small weight hung from the bottom of the tube, which is then drawn over a distance of about 10 ft. The uniformity and straightness of the bore of the piece of drawn tubing may then be checked by viewing the bore by microscope through the wall of the tube. Fine capillaries of less than 10 μ diameter may also be drawn by hand, the advantage of this method being that it is possible to thicken up the wall of the tube before drawing to ensure that the external diameter of the drawn tube does not become too small and the tube thus fragile. However, drawing by hand has not been found to be a reliable method for the production of straight tubes although some successes have been attained.

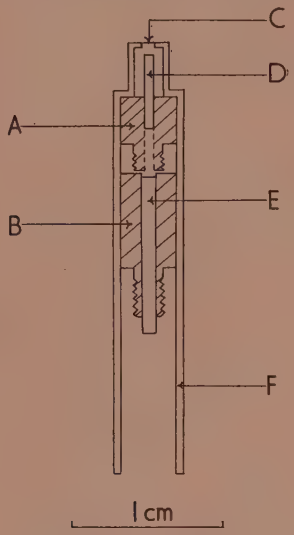


Fig. 2. Diagram of collimating system

A, B, brass cylinders; *C*, Formvar window; *D*, glass capillary; *E*, polonium source on platinum wire; *F*, brass sleeve.

The glass capillary is mounted in the cylinder *A* so that approximately 3 mm of the tube projects beyond the surface of the cylinder. The lower end of the cylinder is threaded so that it may be held in an adaptor during insertion into the brass sleeve.

The polonium source was deposited on the end of a platinum wire 0·9 mm diameter 3 cm long which was mounted in the cylinder *B* so that the active end was just below the top surface of the cylinder. This cylinder was also threaded on its lower end.

It was found that the diameter of the collimated beam was reduced by evacuation of the tube through which the α-particles pass and that simultaneously an increase in the rate of emergence of particles from the collimator was obtained. The spread of the beam above the geometrical size is due to gaseous scattering occurring both in the tube and after emergence of the particles from the end of the tube. The rate of emergence of particles from the tube is increased by a factor of three by evacuation, since particles pass through the tube which would otherwise be lost by scattering.

The gaseous scattering of the beam after emergence from the collimator necessitates the end of the collimating tube being as near to the irradiated specimen as possible. Since it was not possible for the irradiated specimen to be *in vacuo*, it was arranged that the collimating system could be evacuated, and that the window through which the particles emerge when collimated could be brought as close to the specimen as possible.

The upper surface of the collimator sleeve is sealed with a thin Formvar film of weight 0·3 mg.cm^{-2} waxed on to the surface. A rubber tube is attached to the bottom of the sleeve and passes through the substage phase plate which is made of perspex and drilled with a central $\frac{1}{4}$ in diameter hole. The vacuum maintained in the system is 1 mm of mercury which is sufficient to eliminate gaseous scattering of the beam.

RADIOACTIVE SOURCE

The polonium source was prepared by the Radiochemical Centre, Amersham, and was electrolytically deposited on the end of a platinum wire. The activity of the source on preparation was 5 mc corresponding to a specific activity of 0·6 c.cm^{-2}. This specific activity was the maximum that could be obtained by this method of deposition.

If the assumption is made that α-particles enter the collimating tube from that portion of the source which is equal in area to the cross-sectional area of the collimating hole, and that a source of this strength is concentrated on the axis of the tube, it may be shown that the rate of emergency of the particles from the collimator is $1{\cdot}1\times10^9 Sd^4/l^2\text{min}^{-1}$, where d and l are the diameter and length of the collimating tube in millimetres, and S the specific activity of the source in curie (centimetres)$^{-2}$. This assumption is justified for this geometry, more exact calculations for the solid angle subtended by a uniform spread source(5) leading to the same result. For a tube of 15 μ diameter, 5 mm long, the calculated emergence rate for a source of 0·5 c.cm^{-2} is 1·1 min^{-1}. It may thus be seen that a high specific activity of the source is required to obtain a sufficiently high rate of emergence of particles from the collimating tube.

Care must be taken when assembling the parts of the collimating system to avoid the possibility of polonium contaminating the upper part of the brass sleeve. If this occurs particles may emerge from the upper end of the assembly which have not passed through the collimating system, thus greatly increasing the beam diameter. Contamination of metal surfaces adjacent to a polonium source readily occurs due to the phenomenon of "creeping" of polonium and it has not been found possible to re-use the same metal parts if the collimating tube system has to be reassembled.

INVESTIGATION OF BEAM DIAMETER

The diameter of the beam in the plane of irradiation was investigated by exposing an Ilford C.2 nuclear research emulsion plate on the stage of the microscope so that α-particles from the collimator entered the plate normally.

ter processing, examination of the plate enables the residual ergy of the α-particles to be determined by measurement the range of the track in the emulsion. The position of ch track is indicated by a black dot, since the tracks are rmal to the focal plane of the observing microscope and us the position of every particle entering the emulsion ay be determined, and from the total number of dots the te of emergence of particles from the collimator may be und.

Fig. 3 shows an analysis of the positions of the particles on otographic plates exposed in this way plotted as percentage f the total number of particles on the plate which lie within a rcle of diameter *D* given by the abscissa. Curve *A* was btained with the collimator assembly evacuated, the end f the collimator being 0·2 mm from the emulsion. Curve *C* as obtained in the same conditions with the collimator ssembly at atmospheric pressure. Curve *B* shows the addi-onal scattering when the collimator under conditions *A* lowered by a further 1 mm from the plate.

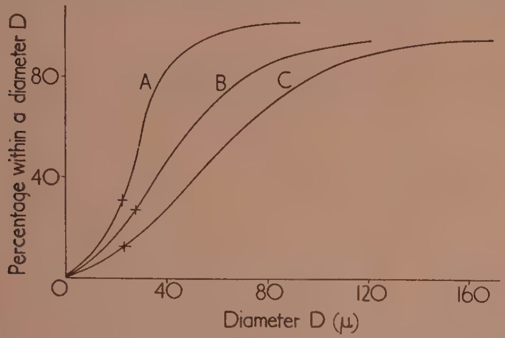


Fig. 3. Investigation of α-particle beam diameter
+, geometrical diameter of beam.

The range of the particles in processed emulsion was 8 μ nd, allowing for the shrinkage factor of the emulsion, corre-ponds to an α-particle energy of 4·8 MeV. All the particles merging from the collimator have the same range in the mulsion so that the beam is monoenergetic.

BEAM ALIGNMENT

It is clearly necessary that the beam should be in the centre f the field of view of the objective. To facilitate this adjust-ent, the objective is mounted in a centring ring so that it ay be moved laterally relative to the tube of the microscope.

A brass template, shown in Fig. 4, was machined with ccurately parallel surfaces so that the thickness of the plate as equal to the distance between the lower surface of the oist cell and the coverslip enclosing the cell. This template as rigidly fixed to the microscope stage. In position its oper surface is coincident with the plane of the irradiated ecimens in the moist cell. The emulsion of a photographic ate placed with its sensitive side down thus occupies the same position as the irradiated specimen in the moist cell. The template is fitted with three knife-edges made from pieces of razor-blades and the photographic plates were pressed by hand against these blades. It was found that a plate could be repeatedly replaced on the template with a maximum positional error of ± 1 μ by lightly pressing it against the knife-edges of the template.

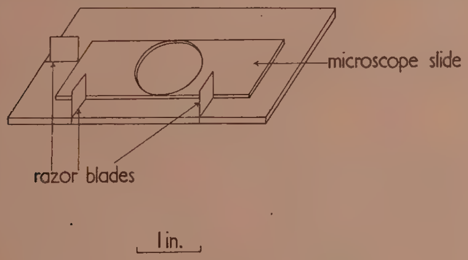


Fig. 4. Brass template

A plate was exposed in position on the template and developed. The position of the centre of the α-particle beam was then found with a microscope using a low power objective by viewing the emulsion through the glass backing of the plate. On the back surface of the plate, a cross was scribed using a diamond point mounted in the nose piece of the microscope, the cross being coincident with the centre of the α-particle beam on the emulsion side of the plate.

The plate was then replaced on the template and the objective moved until the cross-line appeared in the centre of the field. Repeated exposures were made by this method to check the alignment of the beam with satisfactory results.

STATISTICS OF IRRADIATION

From the plate the mean rate of arrival of particles can be determined. This rate decreases constantly due to the decay of the polonium source with a half-life of 138 days. The time intervals between arrival of successive particles follow a Poisson distribution so that the probability $P(n)$ of n particles striking the specimen in a time t when the average number is $\bar{N}t$ is given by

$$P(n) = (\bar{N}t)^n . e^{-\bar{N}t}/n!$$

If a time scale is chosen such that unit time is equal to the average time interval between arrival of successive particles then $\bar{N} = 1$.

Using this time scale the probability that no particle strikes the specimen in unit time is given by the value of $P(n)$ when $n = 0$ and $t = 1$ and is equal to 1/e. Thus the probability of one or more particles striking the specimen in unit time is equal to $(1 - 1/e)$. In the same way it may be shown that the probability of one or more particles striking the specimen in a time t is equal to $1 - e^{-t}$.

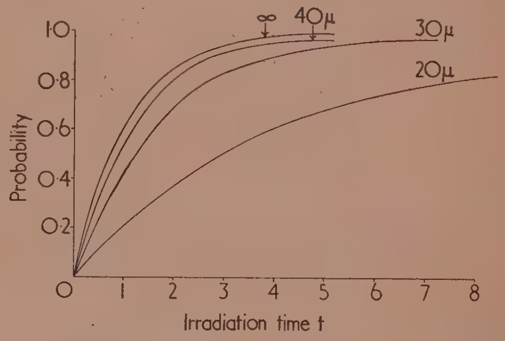


Fig. 5. Probability of one or more α-particles striking a circular target of diameter as shown if irradiated for a time t, the units of time being such that $\bar{N} = 1$

Suppose that the target area is circular in shape with its centre coincident with the centre of the beam and of area such that a fraction K of the total number of particles striking the specimen strike the target. The effective value of $\bar{N}$ for the target is reduced to $K\bar{N}$ so that the probability $P_A(n)$ of the area A being struck by n particles in a time t when the average number striking the target is $K\bar{N}t$ is given by

$$P_A(n) = (K\bar{N}t)^n e^{-K\bar{N}t}/n!$$

Using the time scale where $\bar{N} = 1$, the probability of one or more particles striking the area A in time t is given by $(1 - e^{-Kt})$.

The experimental values of K may be determined from Fig. 3, and Fig. 5 shows the probability of one or more particles hitting targets of different diameters as a function of the irradiation time t.

BIOLOGICAL MATERIAL

The apparatus described above is being used in an investigation to irradiate the generative nucleus inside the pollen tube of *Tradescantia*. Pollen is cultured in a moist atmosphere on an agar medium on the coverslip enclosing a moist cell. This cell is made of perspex and contains a ring of moistened filter paper to maintain the humidity inside the cell.

ACKNOWLEDGEMENTS

The author is indebted to Dr. L. H. Gray and Dr. S. R Pelc for the suggestion of the general plan of the experiment and to the British Empire Cancer Campaign for financia assistance. The early part of this work was undertake whilst the author was in receipt of a Junior Fellowship o the Campaign.

REFERENCES

(1) Nickson, J. J. (Editor). *Symposium on Radiobiology* (London: Chapman and Hall Ltd., 1952.)

(2) Lea, D. E. *Action of Radiation on Living Cells.* (London Cambridge University Press, 1946.)

(3) Zirkle, R. E., and Bloom, W. *Science*, **117**, p. 487 (1953)

(4) Templeton, C. C. *Rev. Sci. Instrum.*, **24**, p. 880 (1953).

(5) Jaffey, A. H. *Rev. Sci. Instrum.*, **25**, p. 349 (1954).

On the preparation of precision resolving-power test objects

By G. D. Dew, National Physical Laboratory, Teddington, Middlesex

[*Paper first received* 21 *September, and in final form* 6 *October*, 1954]

A method is described of producing large ranges of Cobb-type test objects of unusually high dimensional accuracy. A precisely constructed "master chart" comprising five groups of targets is used to produce a series of reduction negatives, which, when suitably mounted, are further reduced to the required dimensions.

For testing the resolving-power of optical instruments, various types of target have been suggested. Charts of the Cobb-type⁽¹⁾ are commonly employed, consisting of isolated groups of two or more lines, each group being of successively smaller spacing than the one preceding. If it is required to test a large range of optical instruments, a correspondingly large range of targets is necessary, and in order that the precision of the resolving power determinations may be maintained, the spacing increment between adjacent groups must be small. Further, it is desirable that the complete range of targets be grouped as compactly as possible near the axis of the collimator. Alternatively, it must be arranged to bring each target in turn on to the axis of the optical system.

The graticules, the preparation of which forms the subject of the present communication, were required to be of an unusually high precision. A range of three-bar test-objects was required of from 2·5 to 60 lines per mm, the line spacing of adjacent groups being in the ratio of 1·05. It was considered desirable that the width of the lines and of the spaces between them should be within 1% of the specified nominal dimensions. Five pairs of patterns (enlarged) are shown in Fig. 1.

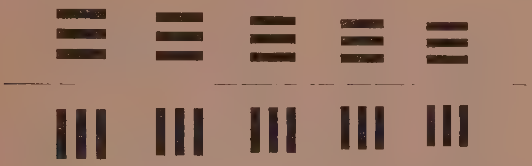


Fig. 1. Five pairs of test objects (enlarged)

The following possible sources of error were considered:

(*a*) errors in the original drawing;
(*b*) errors in reduction;
(*c*) unsharpness of lines due to inferior lens performance;
(*d*) exaggeration of line thickness due to faulty exposure and processing in combination with (*c*).

The proposed method of preparation of the graticules was as follows. Firstly, a precise "master chart" of five sets of targets was to be prepared of thin metal foil mounted on glass. It was anticipated that the metal-on-glass master would have two principal advantages over a chart prepared by norma drawing methods. Not only would it be capable of much more precise construction, but the provision of uniform illumination would be very much simpler than if reflected light were employed. From this master chart, a series of reduction negatives would be prepared, which when mounted in line would provide an enlarged negative facsimile of the final graticules. Finally, this "master negative" was to be further reduced to the required dimensions.

Preliminary experiments showed that the main difficulties to be encountered were due to the need for an objective having both a high resolving power and a large angular field. The graticules under consideration were to contain sixty-five pairs of targets occupying a total length of 40 mm and a maximum width of 3 mm. The finest lines required were 0·008 mm wide and these were not merely to be resolved, but to be sharply defined and of precise width. It was evident that a photographic objective, although providing the necessary field, would have a resolving power quite inadequate for the purpose. On the other hand, a microscope objective which would give the necessary resolution, would cover only a fraction of the field required, and would necessitate a number of separate exposures, the plate being moved laterally between each. Thus, a 16 mm microscope objective with a useful field of 0·75–1 mm diameter if used to produce such a graticule would require approximately eighty separate exposures, and precision movements of the plate in two perpendicular directions would be needed. It was decided that such an elaborate procedure could be avoided, without seriously impairing the usefulness of the charts, by dividing them into two ranges. The division would be so arranged that the coarser of the two could be satisfactorily produced with a high quality photographic objective, while a microscope objective would be used only for the fine range. By this means, the number of separate exposures required would be considerably reduced and further, precision movement of the plate would be restricted to one direction only owing to e reduced width of the finer graticule. For convenience, the vision was made so that a single master negative would ffice for both ranges, namely:

Range 1, 2·5 to 15 lines per mm; overall dimensions 36 × 3 mm:
Range 2, 10 to 60 lines per mm; overall dimensions 9 × 0·75 mm.

PREPARATION OF THE MASTER CHART

A series of precision-ground steel blocks was prepared, ıe for each of the five patterns of the master chart. The mensions were chosen for convenience in manipulation, e largest being 30 × 6 mm and the remainder being smaller successive factors of 1/1·05. These gauges were used stly as templates for cutting the metal foil and secondly as pacers during the process of mounting the strips on glass. he foil used was 0·001 in. aluminium, flattened by a suitable eat treatment and each strip was provided with two punched oles 2–3 mm in diameter for fixing purposes. The adhesive nployed was hard vacuum wax applied in the form of a ead on the end of a length of wire as shown in Fig. 2. laving located the aluminium strip in the required position, ıe wire carrying the bead of wax was lowered mechanically as to touch the glass exposed by the hole in the metal strip ithout coming into contact with the metal itself. Appliation of heat to the upper portion of the wire then caused ıe wax to melt and seal the metal to the glass, the wire being multaneously withdrawn. This method of mounting has een found to give charts of high precision and of a high egree of permanency. Measurements on the completed chart showed that both lines and spaces were within ±0·3% of the nominal dimensions, representing total errors of cutting and mounting of approximately 0·0006 in. (0·015 mm). To provide a means of alining the reduction negatives, a length of 0·010 in. steel piano wire was stretched down the centre of the five pairs of targets.

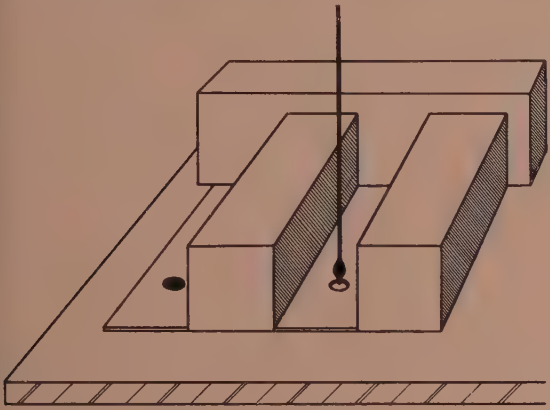


Fig. 2. Method of preparing master chart

First reduction and preparation of the master negative. Throughout this stage of the process, a 13·5 cm $f/4{\cdot}5$ Zeiss Tessar lens stopped down to $f/8$ was employed. The master chart was illuminated by transmitted light provided by a sheet of flashed opal glass and suitably placed lamps; and, to ensure that it was parallel to the camera back, an optical autocollimation method was employed. Eight negatives were prepared of reductions:

$$4,\ 4(1{\cdot}05)^5,\ 4(1{\cdot}05)^{10},\ \text{etc.}\ \ldots$$

The negative materials employed were Ilford Process and Ilford High Resolution plates. After the waste glass had been cut away, the eight negatives were mounted on a piece of $\frac{1}{4}$ in. plate glass using the image of the centre wire for purposes of alinement.

The completed negative comprised forty pairs of targets of line widths ranging from 1·5 to 0·224 mm (0·33 to 2·23 lines/mm). Measurements showed the maximum errors in line width and spacing to be within 0·8% of the nominal dimensions, although the majority of targets were in error by no more than half this amount.

Final reduction—Range 1. After experiments with a number of photographic objectives, a $10\frac{1}{2}$ in. $f/6$ Aviar lens was selected for its high standard of performance. Stopped down to $f/8$, its theoretical resolving power was approximately 190 lines/mm; and, working at a reduction of 7·5, the semi-angular field employed was 3·4°. An autocollimation method was again employed to ensure that the master negative was parallel to the plane of the photographic plate. Kodak Maximum Resolution plates were used, processed according to the makers' instructions. In this final stage, careful control of exposure and processing conditions was found to be of supreme importance, the effect of increased exposure being to broaden the lines and reduce the widths of the spaces between. The ratio of line width to space width was, however, found to provide a convenient criterion of exposure, interpolations being made from measurements on a series of plates given a suitable range of exposures and processed under standard conditions. A suitably exposed plate was found to have an image density in the range 2·0 to 2·5 which is accepted as being adequate for graticules of infinite contrast.

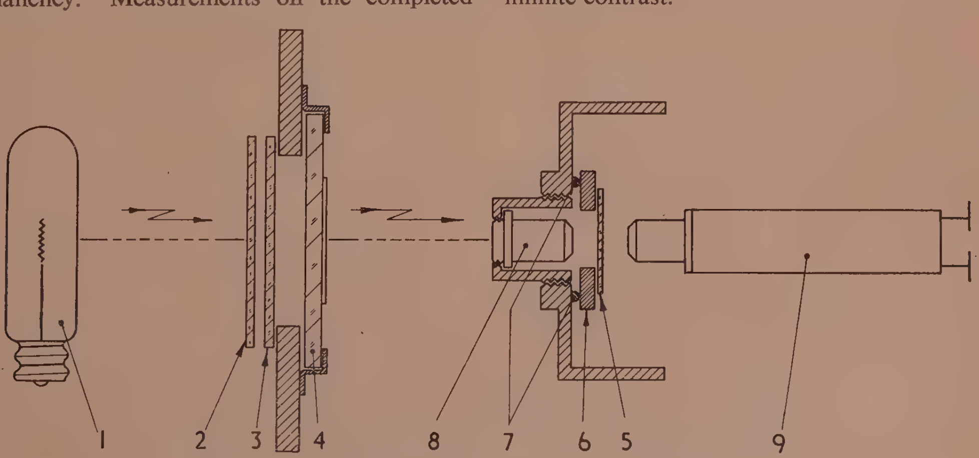


Fig. 3. Apparatus used for final reduction (Range 2)

Final reduction—Range 2. For the final reduction of 30, a selected Beck 16 mm microscope objective was employed having a numerical aperture of 0·28. The theoretical resolving power was approximately 830 lines/mm. Preliminary experiments showed that it could be used at the required conjugates (approximately 480 mm and 16 mm) without any detectable deterioration of performance. Diffuse illumination was used in preference to a point source and condenser system, it being shown that the former would give as good resolution without the disadvantage of accentuating minute blemishes on the negative.

A diagram of the apparatus is shown in Fig. 3. A 300 W projector lamp (1) was used to illuminate a sheet of flashed opal glass (2). The light was then passed through a Wratten K2 filter (3) to restrict the spectral sensitivity of the photographic plate. The master negative (4) was mounted so as to be movable laterally against a fixed scale. The camera, which was specially constructed for the purpose, embodied a micrometer head which allowed controlled lateral movement of the photographic plate while maintaining it at a constant distance from the objective. This was achieved by locating the emulsion side of the plate (5) against a ground and lapped parallel-faced steel frame (6) which in turn was spring-loaded against three fixed steel balls (7). It was estimated, from the quality of the results obtained with this camera, that the plate did not deviate from its nominal plane by more than ±0·0002 in. The taking objective (8) was fitted in a fine screw focusing mount. A visual focus was determined by means of an auxiliary microscope (9), but an exploration on either side of this was found to be necessary to establish the best actinic focus. In preparing each graticule, ten separate exposures were made, the steps being so arranged that in no case was a field greater than 1 mm in diameter employed. The criterion of exposure already described wa again employed, and exposure and processing conditions wer found to be even more critical than with Range 1. Th apparatus was set up on standard optical bench equipmen and was found to be quite sensitive to vibration due t external disturbances. For this reason the final graticule were prepared at night.

Measurements on the finished graticules with a tool-roo microscope showed that Range 1 was well within the stipulate tolerance of ±1%. The method was not precise enough t make an accurate determination on Range 2, but it wa estimated that the probable errors did not exceed ±2%.

Although the graticules were originally prepared for on specific purpose, they have been found useful in othe investigations involving the measurement of resolving powe One such application has been described elsewhere.(2)

ACKNOWLEDGEMENTS

The author wishes to make acknowledgement to Mr. K. Habell for the suggested method of constructing the maste chart and for helpful discussions throughout the course o the work. Acknowledgements are also due to Mr. J. W Woodhouse for his share in the construction of the maste chart. The work described above has been carried out a part of the research programme of the National Physica Laboratory and this paper is published by permission of th Director of the Laboratory.

REFERENCES

(1) Cobb, R. W., and Moss, F. K. *J. Franklin Inst.*, **205** p. 851 (1928).
(2) Sproson, W. N. *B.B.C. Quart.*, **8**, p. 55 (1953).

Analysis of ortho- and para-hydrogen mixtures by the thermal conductivity method

By A. T. Stewart Ph.D.,* and G. L. Squires, Ph.D.,† Cavendish Laboratory, Cambridge

[*Paper received* 13 *August*, 1954]

The thermal conductivity method of measuring the proportion of ortho to para molecules in a sample of hydrogen has been developed and an accuracy of about 0·1% in the measurements has been attained. A description of the method is given.

1. INTRODUCTION

Hydrogen consists of a mixture of two types of molecule, ortho-hydrogen, in which the two proton spins are parallel, and para-hydrogen, in which they are anti-parallel. There are a number of possible methods of measuring the proportion of ortho to para molecules in a sample of hydrogen gas. Among these are

(1) transmission of slow neutrons,
(2) nuclear resonance methods,
(3) velocity of sound measurements,
(4) vapour pressure measurements,
(5) thermal conductivity measurements.

The first three methods(1) involve specialized techniques and are not usually convenient. The vapour pressure an thermal conductivity methods have both been used in th past, and we shall compare them briefly before proceedin to a detailed description of the latter method.

The difference between the vapour pressures of the tw forms of hydrogen at 20·4° K is about 50 cm of oil (sp. gr. =1) Thus, if the pressure can be read to 0·05 cm, the ortho-para composition can be measured to 0·1%. (Throughout thi paper we shall specify the composition of ortho-para mixture by the para-hydrogen content expressed as a percentage. A 1% change in composition will mean a change of one uni in the percentage para-hydrogen content.) The vapou pressure method has been used on several occasions,(2,3) bu though simple in principle it has some disadvantages. It i necessary to liquefy part of the gas and hence a rather larg sample (about 300 ml at N.T.P.) must be used. The metho also requires a temperature of 20° K and this is often no readily available.

---

* Now at Atomic Energy of Canada Ltd., Chalk River, Ontario, Canada.

† Now at the Institute for Nuclear Studies, University of Chicago, U.S.A.

The thermal conductivities of ortho- and para-hydrogen e shown in Fig. 1. The analysis of ortho-para mixtures by eans of thermal conductivity measurements was first rried out by Bonhoeffer and Harteck.(4) The method has veral advantages. Small quantities of gas (about 30 ml. at .T.P.) are required; the apparatus is easy to construct; the easurements are relatively simple and with care the com- sition may be determined to about 0·1%. A brief account

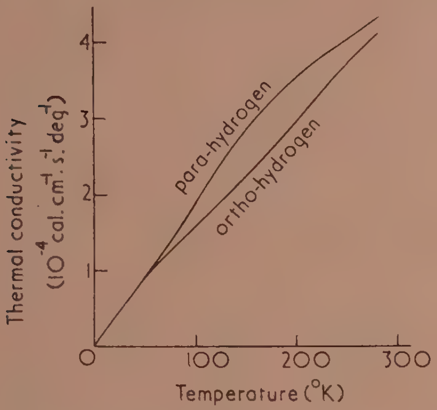


Fig. 1. Thermal conductivities of ortho- and para-hydrogen

the method has been given by Farkas(5) and others.(6,7) ur original apparatus was based largely on the description ven by Farkas but failed to yield the accuracy that he aimed. Modifications were therefore introduced to make e apparatus more sensitive and more consistent in its sults.

2. DESCRIPTION OF THERMAL CONDUCTIVITY METHOD

troduction

In the method to be described the gas is admitted to a lindrical glass cell immersed in a dewar of liquid nitrogen. n electrically heated wire is located along the axis of the linder. The current through the wire and the pressure of e gas are kept constant. Under these conditions the quilibrium temperature of the wire, found by measuring its sistance, depends on the thermal conductivity of the gas. o determine the ortho-para composition, it is not necessary calculate the thermal conductivity explicitly from the easurements. Instead, the relation between the wire sistance and the composition of the gas is determined rectly by means of known mixtures of ortho- and para- ydrogen. The composition of an unknown mixture is then tained by measuring the corresponding wire resistance.

escription of apparatus

(*a*) *Conductivity cell.* The cell is shown in Fig. 2. The as is contained in the glass cylinder *A*, 15 cm long and 3 cm diameter. The filament is a tungsten wire 2·6 cm long d 0·0012 cm in diameter. Previous workers have used atinum filaments but we found that tungsten gave more nsistent results, possibly due to the fact that platinum sorbs hydrogen. The length of the filament was chosen that the voltage across it, under working conditions, could read directly on a 1·9 V potentiometer.

The current and potential leads to the filament were mounted an evacuated glass tube *B*. This method(6) of connecting parts which are at very different temperatures in the apparatus eliminates resistance fluctuations in the wires due to convection currents. The filament *J* was spot-welded between two thin nickel strips which were in turn spot-welded to tungsten rod supports. The current leads were attached to these rods.

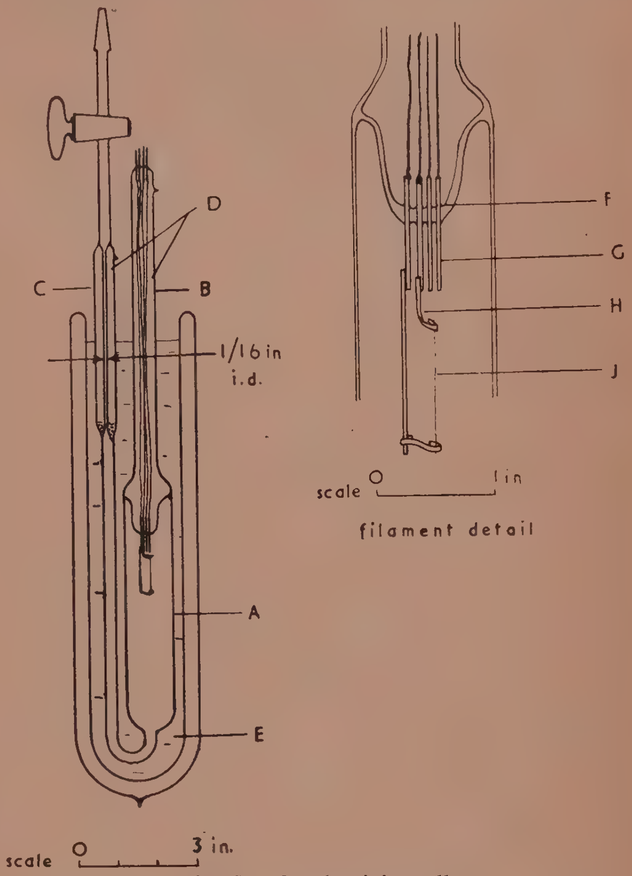


Fig. 2. Conductivity cell

A, glass cylinder; *B*, evacuated glass tube; *C*, Dewar tube; *D*, sealed vacua; *E*, liquid nitrogen; *F*, tungsten-Pyrex seal; *G*, tungsten rods; *H*, nickel strip; *J*, tungsten filament.
The connexions between the tungsten rods and the nickel strips in the potential circuit are omitted to avoid confusion.

Owing to the difficulty of mounting, the potential leads were spot-welded not to the filament itself but to the nickel strips.

The Dewar tube *C* reduced considerably the pressure and resistance fluctuations due to small changes in the level of the liquid nitrogen bath.

(*b*) *External electric circuit.* The electric circuit is shown in Fig. 3. The value chosen for the filament current was 165·00 mA. (The factors governing the choice of filament current and gas pressure are discussed in Section 5.) To ensure that the current remained constant it was found necessary to use a stabilization circuit. The resistance *D* was adjusted so that the 24 V supply provided 90% of the filament current. Under these conditions the voltage across the points *X* and *Y* was determined almost entirely by that of the cells *F*. As these were of 90 amp-h capacity and were passing only 16 mA, their voltage changed very little. The cell current was determined by measuring the voltage drop across the 10 Ω standard resistance *G* connected in series with the filament. The current was set at its operating value by means of the variable decade resistances *H* and remained within 2 parts in 10^5 of this value during each resistance measurement. The latter was carried out by measuring the voltage E across the potential terminals of the filament.

(*c*) *Associated glass apparatus.* The pressure p of the gas in the cell was measured on a manometer containing dibutyl phthalate oil. The zero-pressure side of the manometer was pumped during measurements. As the gas in the tube connecting the cell to the manometer was exposed to temperature variations, due to draughts across the tube, the volume of this tube was made small compared with the volume of the cell.

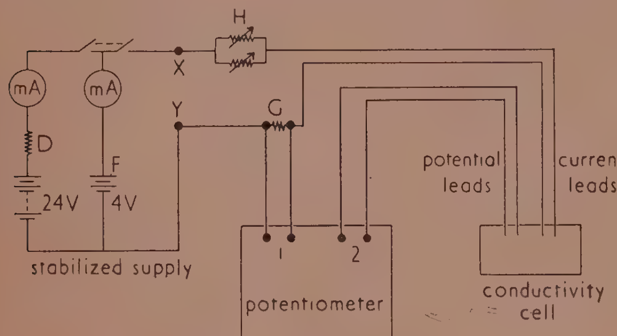


Fig. 3. Electrical circuit

For calibration purposes, samples of hydrogen gas of known composition were available in flasks permanently attached to the apparatus. A mechanical device for mixing two standard gases in known proportions was also attached to the system.

3. PROCEDURE FOR MAKING MEASUREMENTS

A fixed time-table was found to be necessary in the measurement of the filament voltage E, because first, the voltage rose continuously for about 6 min after the sample was introduced and secondly the liquid nitrogen gradually boiled away and exposed an increasing length of the tube C (Fig. 2) to a temperature above 78° K.

No measurements were made therefore until 8 min from the time when the gas was admitted to the cell, this time being taken as zero. The filament current was switched on immediately after the gas was admitted. The pressure p was then adjusted until it was within 0·5 cm of the standard pressure $p_0 = 50{\cdot}00$ cm. The voltage E was measured at 8, 10 and 12 min. The liquid nitrogen jacket was filled to a constant level at 7, 9 and 11 min. Before each voltage measurement the current was adjusted to its operating value and after each measurement the pressure was read. The potentiometer was standardized at 6 min, and 2 min were allowed for pumping out the sample. Thus with the above routine a sample could be analysed every 15 min.

The mean values of E and p were taken. Then knowing the pressure sensitivity (dE/dp) of the apparatus, we converted E to the value E_0 corresponding to the standard pressure p_0.

If the pressure was lowered or the current increased to such an extent that the temperature of the filament went beyond its normal range, the results for the following hour or so tended to be unreliable. The inadvertent pumping out of the sample from the cell before the current was switched off resulted in a temperature so high that a complete recalibration was necessary.

4. CALIBRATION OF APPARATUS

The relation between the voltage E_0 and the para-hydrogen content was found by first measuring E_0 for three standard mixtures, namely 25·1, 49·7 and 99·8% para-hydrogen. These are the equilibrium mixtures at room, liquid nitrogen and liquid hydrogen temperatures respectively. Other samples were then prepared by mixing the standard gases in a known ratio and E_0 was measured for each sample. The results are shown in Fig. 4. The relation between E_0 and the para-hydrogen content was found to be not quite linear, the deviation from linearity amounting to about 5% in the range 25 to 100% para-hydrogen.

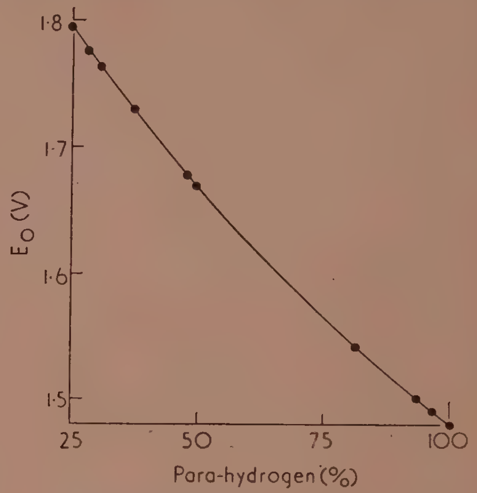


Fig. 4. Calibration of apparatus: relation between E_0 and percentage of para-hydrogen

The characteristics of the cell were found to vary slightly through the course of a day, the variation being equivalent to about $\frac{1}{2}$% in ortho-para composition. To correct the error due to this variation, samples of standard gas were analysed from time to time and the cell calibration changed correspondingly. Because liquefaction was our most convenient method of purifying hydrogen, all our standards were taken from hydrogen evaporated from the liquid. Apart from helium, the presence of which was unlikely, all impurities were thus removed.

5. CHOICE OF OPERATING CONDITIONS

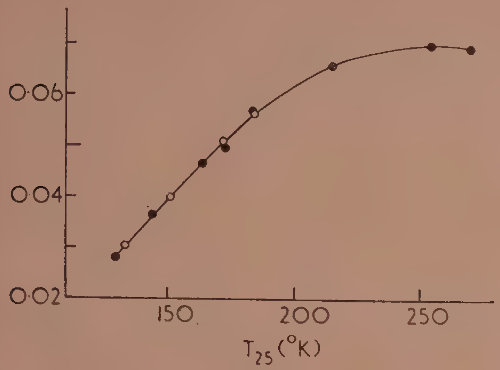
The operating conditions, namely the values of the filament current and the standard gas pressure, were chosen so that the sensitivity of the apparatus to changes in ortho-para composition was near to its maximum value. In order to measure the sensitivity, mixtures of 25 and 50% para-hydrogen were prepared and the voltage E measured for each mixture, the cell current and the gas pressure being the same for the two measurements. Measurements were made with various currents and pressures.

The quantity

$$S = (E_{25} - E_{50})/E_{25}, \qquad (1)$$

where the subscripts denote the percentage of para-hydrogen in the sample, was taken as a measure of the sensitivity. The results are shown in Fig. 5 where S is plotted against T_{25}, the equilibrium temperature of the wire for a mixture of 25% para-hydrogen. It was found that the quantity S depended only on T_{25} and not on the particular combination of current and pressure that was used. From the results in Fig. 5 it can be seen that the sensitivity had a rather flat maximum at about 250° K.

he choice of the pressure was not critical. For a fixed ue of T_{25}, increasing the pressure caused the pressure sen- vity to decrease. It was clearly desirable that the error E_0, caused by the uncertainty in the pressure reading, uld be small compared with the uncertainty in measuring on the potentiometer. For T_{25} in the neighbourhood of ° K, this was found to be the case provided the pressure s greater than about 30 cm of oil.



ig. 5. Experimental results showing how the sensitivity, —defined in equation (1)—varied with T_{25}, the tem- erature of the filament corresponding to 25% para-hydrogen

○ Results for p_0 = 30 cm of oil.
● Results for p_0 = 50 cm of oil.

he operating conditions of the cell and the sensitivity of apparatus under these conditions are summarized in the le.

Operating conditions and sensitivity of cell

erating conditions		
Current (mA)	165·00	
tandard pressure p_0 (cm of oil)	50·00	
	25% para	*100% para*
ilament temperature T (°K)	220	180
otential E_0 across filament (mV)	1795	1480
sitivity		
ressure sensitivity dE/dp (mV/cm of oil)	8·2	4·9
hange in E_0 for 1% change in ortho-para composition (mV)	5·4	3·0

t may be noted that our range of filament temperatures higher than 160–180° K, the temperature range in which specific heat difference between the two forms of hydrogen maximum and the range recommended by Farkas. A ple theoretical analysis shows that, in accordance with measurements, the sensitivity is greater for the higher ge.

6. ACCURACY

The potentiometer could be read to an accuracy of 0·2 mV, but in practice it was found that successive samples of gas with the same ortho-para composition gave values of E_0 that differed by about 0·5 mV. The pressure could be read to 0·02 cm of oil and this was equivalent to an error of about 0·1 mV in the value of E_0. Thus the total uncertainty in E_0 was between 0·5 and 0·6 mV. For 25% para-hydrogen, a 1% change in composition gave rise to a change of 5·4 mV in E_0. Therefore the total error was 0·1%. For 100% para-hydrogen, a 1% change in composition gave rise to a change of 3·0 mV in E_0, and the error was therefore 0·2%.

Fig. 6 shows some typical results obtained with the apparatus. The measurements were made during an experiment on the scattering of slow neutrons by normal (i.e. 25% para) hydrogen.$^{(8)}$ The gas was maintained at a temperature of 20·4° K during the experiment and was converting slowly into the para form. Samples were removed from time to time and analysed in the cell. A least squares analysis shows that the r.m.s. error in a single observation was 0·13% in the ortho-para composition.

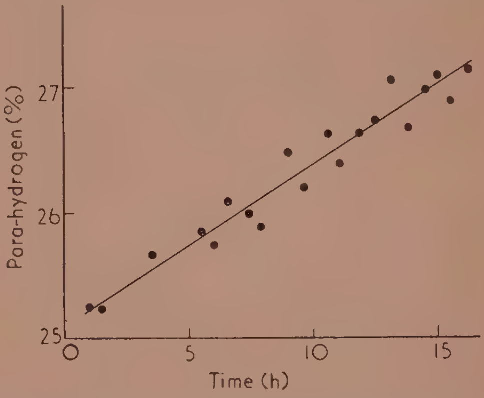


Fig. 6. Typical set of results obtained with conductivity cell: analysis of samples taken from a specimen of normal hydrogen that was converting slowly into the para form

REFERENCES

(1) Some results obtained by the nuclear resonance method are given by PURCELL, E. M., POUND, R. V., and BLOEMBERGER, N. *Phys. Rev.*, **70**, p. 986 (1946).
(2) WOOLLEY, H. W., SCOTT, R. B., and BRICKWEDDE, F. G. *J. Res. Nat. Bur. Stand.*, **41**, p. 379 (1948).
(3) SWENSON, C. A. *J. Chem. Phys.*, **18**, p. 520 (1950).
(4) BONHOEFFER, K. F., and HARTECK, P. *Z. Phys. Chem.*, **B.4**, p. 113 (1929).
(5) FARKAS, A. *Light and Heavy Hydrogen* (London: Cambridge University Press, 1935).
(6) TAYLOR, H. S., and DIAMOND, H. *J. Amer. Chem. Soc.*, **57**, p. 1251 (1935).
(7) WIRTZ, K. *Z. Phys. Chem.*, **B.32**, p. 335 (1936).
(8) STEWART, A. T., and SQUIRES, G. L. *Phys. Rev.*, **90**, p. 1125 (1953).

The necessary torque requirements for a servo-motor

By J. C. West, Ph.D., A.M.I.E.E., and J. L. Leonard, B.Sc., Electrical Engineering Department, The University of Manchester

[*Paper first received* 3 *June, and in final form* 25 *October*, 1954]

The case is taken where the most stringent condition that is demanded of a remote-position-control system containing friction and inertia, is a maximum acceleration. It is shown that the (torque)²/inertia ratio of the servo-motor itself must be greater than a certain value if this maximum acceleration is to be achieved. This value is a function of load inertia, friction and the maximum acceleration required.

One of the most important considerations in the design of any type of control system is the choice of the driving motor which must be capable of supplying the necessary energy to the load under the most strenuous running conditions. The selection of a suitable motor is usually difficult, the designer using in turn the data of each motor of all those available to him until a satisfactory machine is obtained.

The design problem lies in the fact that there is no general relationship between torque and inertia since the factors involved vary according to the manufacturers. Power is often used as a basis for calculation but, since for a given speed power is proportional to torque, the problem is still essentially the same.

A control system is usually designed to meet certain specific requirements and often the most difficult one can be represented as a certain maximum acceleration of the load at a given speed. The paper is devoted to the development of a suitable criterion which must necessarily hold for all motors to enable this maximum acceleration to be achieved. Use of this criterion will enable the designer to rule out a large number of motors available to him as being incapable of producing the required maximum acceleration. Selection from those motors for which the criterion holds can be based on other requirements of the particular system.

TORQUE FOR A GIVEN ACCELERATION

The inertia of the servo-motor is an important factor in design since it determines the proportion of the total torque required for the motor itself during an acceleration of the motor and load. The relative accelerations of the motor and load may be varied by placing a gearbox between them and the total torque needed from the motor to accelerate the system may be changed accordingly. There is an optimum gear ratio which minimizes the torque and this is a function of motor inertia.

Consider a motor of inertia I_m lb . ft² with a torque T_m lb . ft, driving a load of inertia I_L lb . ft² and frictional couple $F(\omega)$ lb . ft, through a step down gear ratio $N:1$. Let the required maximum angular acceleration of the load be a rad/s² at a speed ω rad/s. I_L and $F(\omega)$ must include the effective inertia⁽¹⁾ and friction of the gearbox.

The torque required by the load is $F(\omega) + (I_La/g)$ where g is the acceleration due to gravity.

The effect of the gearbox is to multiply by the gear ratio the torque transmitted through it and therefore the torque needed at the motor end of the gearbox to drive the load is:

$$\frac{1}{N}\left[F(\omega) + \frac{I_La}{g}\right]$$

The motor acceleration is aN and the torque required from the motor to cause this is

$$aNI_m/g$$

The excess torque must be sufficient to drive the load.

Hence $$T_m - \frac{aNI_m}{g} = \frac{1}{N}\left[F(\omega) + \frac{I_La}{g}\right]$$

$$T_m = \frac{[I_La + I_mN^2a + F(\omega)g]}{gN} \qquad (1$$

Differentiation with respect to N gives

$$dT_m/dN = (I_ma/g) - [I_La + F(\omega)\,.\,g]/gN^2$$

which must be zero for a stationary value of T_m.

Hence $$N^2 = (I_La + F(\omega).g)/I_ma \qquad (2$$

is found to give a minimum value for the torque.

Eliminating $(I_La + F(\omega).g)$ between equations (1) and (2 gives

$$N = gT_m/2I_ma \qquad (3$$

If any gear ratio other than that specified by equation (3 is used, then a motor of a given inertia will need to supply more torque than would otherwise be the case.

If the frictional forces are negligible, then equation (2 becomes

$$N^2 = I_L/I_m \qquad (4$$

showing that the correct gear ratio is independent of acceleration or velocity.

MAXIMUM ACCELERATION FOR A GIVEN TORQUE

An allied problem is that of determining the correct gea ratio to give the maximum acceleration when the motor torque is fixed.

Equation (1) may be rewritten in the form

$$a = [T_mgN - F(\omega)g]/(I_L + I_mN^2)$$

Differentiation with respect to N gives

$$\frac{da}{dN} = \frac{(I_L + I_mN^2)T_mg - (T_mgN - F(\omega).g)2I_mN}{(I_L + I_mN^2)^2}$$

Equating the right-hand side to zero for a stationary value gives

$$N^2 - [2.F(\omega)/T_m]N - (I_L/I_m) = 0$$

In this application N can only be positive, hence

$$N = \frac{F(\omega)}{T_m} + \sqrt{\left[\frac{F(\omega)^2}{T_m^2} + \frac{I_L}{I_m}\right]}$$

When friction is negligible the optimum gear ratio fo maximum acceleration is

$$N = \sqrt{(I_L/I_m)}$$

which is the same as that obtained [equation (4)] in th previous section to give minimum torque.

OPTIMUM GEAR RATIO

: has been shown that the torque T_m, required of a motor produce a maximum load acceleration a, is minimized by ıg a gear ratio which is a specified function of a. This r ratio only matches the load and motor at the one acce- tion and when the acceleration required is less than a, system becomes mismatched. In this event the torque ded must not be greater than the minimum required at the eleration a.

quation (1) may be used for the torque required,

$$T = [I_L f + I_m N^2 f + F(\omega).g]/gN$$

ere f is now the acceleration assumed less than a and the r ratio N used is such that T_m is the minimum torque to duce the acceleration a, i.e., from equation (3), $N =$ $/2I_m a$. Hence eliminating N gives

$$T = \left(\frac{2I_m I_L a}{g^2 T_m} + \frac{T_m}{2a}\right) f + \frac{2I_m F(\omega) a}{g . T_m} \qquad (5)$$

e relationship between T and f is linear and therefore T l be greatest when f is the maximum acceleration required, , $f = a$. Thus it can now be stated that with the value of given by equations (2) or (3), T_m will be the minimum torque uired for any acceleration up to and including a.

CRITERION FOR THE DRIVING MOTOR

The torque required to give the load an acceleration a is en by equation (1). The optimum gear ratio is given by ıation (2), and elimination of N between these two equations es the minimum torque required as

$$T_m = (2/g) I_m a (I_L a + F(\omega) g] \qquad (6)$$

Regarding the load and the maximum acceleration a as ed let the constant

$$(4a/g^2)(I_L a + F(\omega).g) = K \qquad (7)$$

en equation (6) can be modified to

$$T_m^2 = K I_m \qquad (8)$$

us the necessary criterion which must hold in order that a tor can accelerate a given load by a stipulated amount is

$$T_m^2 / I_m \geqslant K \qquad (9)$$

ıe concept of the (torque)^2/inertia ratio as a design criterion ıot new.)[2, 3]

USE OF THE CRITERION

The value K of the criterion depends only on the load ıstants and load requirements and does not involve any he motor constants. It is assumed that the torque T_m can delivered at the correct speed, i.e. at $N\omega$.

n the majority of servo-systems the torque is the controlled ıntity which can be varied by means of a control signal m a maximum in one direction, through zero, to a maxi- m in the other direction. The maximum torque is ally largely independent of running speed and thus T_m is en quoted by manufacturers as a constant independent of ed.

When using the criterion it is desirable to bear in mind the e of system in which the motor is to be employed. Servo- tors are generally controlled either by varying the arma- e current, keeping the field constant or by varying the l current. In the latter case the armature current is kept sensibly constant over a wide speed range. In both systems the maximum torque obtainable depends on the greatest field, which is limited by saturation, and on the largest armature current, which is limited by copper losses. In field-controlled servo-motors, the maximum armature current is that which can flow continuously at any speed, and it is the greatest torque developed by this current which must be substituted in equation (9) to find the suitability of a machine for such a system. In armature-controlled servo-motors, the current to produce a burst of acceleration may safely be greater than the highest permissible standstill current, since the heating effect is usually greatest at standstill. If, therefore, the maximum standstill torque of the machine is used in the criterion it can reasonably be assumed that the motor will generate this torque at any speed if suitably controlled. In extreme cases it may be found that no single motor has a sufficiently large (torque)^2/inertia ratio. It is, however, apparent that there is no fundamental limitation to the size of this ratio since more than one motor can be used. Thus if n motors each with I_m and T_m are used together the combined ratio becomes

$$n T_m^2 / I_m$$

Using a similar argument with regard to machine design itself, any factor which increases torque at a rate faster than it increases the square root of the inertia, can be used to improve the T_m^2/I_m ratio.

PRACTICAL DATA

Torque and inertia figures for d.c. motors suitable for use in servo-mechanisms have been supplied by five well-known manufacturers. The power ratings varied from 50 W to 5 kW. In the table the torque, inertia and (torque)^2/inertia ratio are given for twenty-one different machines. The (torque)^2/inertia ratio is seen to vary greatly. In this list, machines with similar inertias have the ratios differing by as much as 700%. It

Industrial torque and inertia data

Manufacturer	T_m(*lb.ft*)	I_m(*lb.ft*^{2})	T_m^2/I_m(*lb*)
A	12·5	2·3	68
	8·34	1·1	62·3
	5	1·0	25
	3·335	0·34	32·7
	1·667	0·21	13·2
B	0·781	0·57	1·07
	0·520	0·5	0·5
	0·312	0·144	0·68
	0·208	0·071	0·57
	0·1041	0·061	0·16
C	12·5	6·832	22·9
	8·33	3·808	18·2
	5·00	3·08	8·12
	3·33	1·4	7·9
	1·667	1·248	2·22
D	12·5	0·243	644
	8·33	0·111	625
	3·33	0·090	122·1
E	3·5	0·16	76·5
	2·0	0·0499	80·2
	0·5	0·016	15·65

may also be seen that the bigger machines have not necessarily the larger ratio.

CONCLUSION

The criterion forms a useful servo-design feature since it enables the immediate determination of the acceptability of a given machine. The analysis takes no account of the speed range of the motor and it may be found that a motor which satisfies the criterion cannot, in fact, be used, since the optimum gear ratio forces the machine to run at speeds outside its range. Even under these circumstances it may be found possible to use a gear ratio as near to the optimum as possib to allow the motor to run within its stipulated speed ran and to couple several motors together to achieve the desir acceleration.

REFERENCES

(1) James, H. M., Nichols, N. B., and Phillips, R. S. *Theo of Servomechanisms*, p. 133 (New York: McGraw-H Book Co. Inc., 1947).

(2) Harris, H. *A.I.E.E. Transactions*, **66**, pp. 83–92 (1947

(3) Gutman, A. S. *Nature* [*London*], **165**, p. 72 (1950).

Laboratory and workshop notes

An adjustable bilateral slit for use with a photomultiplier in a soft X-ray spectrometer

By P. Fisher, B.Sc., Grad.Inst.P., Physics Department, University of Western Australia

[*Note first received* 6 *May, and in final form* 27 *May*, 1954]

In recent years photomultipliers have been used for recording the soft X-ray spectra of solids.(1) This involves driving the photomultiplier tube round the Rowland circle with the analyser slit attached. This note describes a slit designed for such a purpose, utilizing the principles described by Roemer and Oetjen(2) and further developed by Christensen,(3) with many of the bulky components eliminated. It is made from thin sheet, non-magnetic stainless steel.

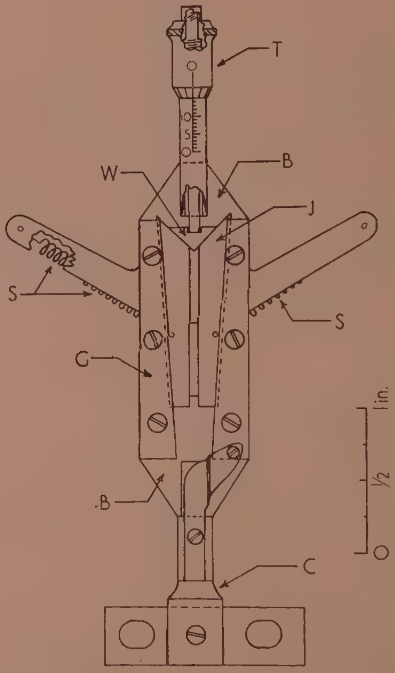
The diagram shows the fully assembled slit opened to its greatest width. The width is changed as follows: clockwise rotation of the micrometer thimble *T* produces downward motion of the wedge-slide *W* which thrusts the two jaws *J* down between the angled jaw-guides *G* causing a decrease in slit width.

The adjusting screw of the micrometer head is made an easy fit in the drum to prevent any tendency to cold welding, correct axial motion being ensured by a neat fit of the screw spindle in a short bush inserted into the bottom of the drum. The wedge slide has a rectangular groove at the top into which the end of the micrometer spindle fits, thus preventing lateral motion and ensuring that the two jaws move down together. The bottom of the groove is bevelled at approximately 1° from the front upwards to the back so that when the screw spindle (which is terminated with a 1° ridge) thrusts the wedge-slide down, the latter tends to be pressed against the main body *B*. The two edges of the wedge-slide in contact with the jaws are rounded so that only line contact is made, thereby minimizing friction and any tendency to jamming.

The maximum motion of the jaws is 9·5 mm producing a variation in slit width from nil to 1·5 mm with an overall slit length of approximately 12·5 mm presented to the radiation. The dimensions of the springs *S* are such that this motion can be nicely handled whilst an even tension prevails throughout the length of travel. The spring strength has been chosen so that the jaws remain stable within the dovetailed jaw-guides.

An adjustable base *C* allows the slit to be set parallel to the grating grooves and in a plane passing through the centre of the Rowland circle. The jaw-guides are made with their screw holes slotted; the whole is then assembled and with the thimble set for zero width the jaws are brought together by movement of the jaw-guides until they are just closed; the jaw-slides are then screwed on tightly. In this way, th need for extreme accuracy in making the other componen is removed.

Although the theory governing the relation of slit wid to assembly constants has already been given,(2) it requir slight modification in the present case. It may be shown th there is likely to be an error of up to 0·004 mm in the sl width due to errors in construction. For various settings the micrometer the actual slit widths were measured with Zeiss comparator, and the mean error was found to be abou 0·003 mm. Reproducibility of widths was such that setting could be obtained to within ±0·002 mm, the error in readin the micrometer and comparator scales.



Mechanical detail of the adjustable slit

Great accuracy in slit width is not essential in the wor for which the slit is intended, but the accuracy could un doubtedly be improved by more careful machining of certai components.

This slit satisfies the requirements of high vacuum wor by the elimination of places which may collect vaporizab or gaseous materials, and in its ease of cleaning an reassembly.

n austenitic type of stainless steel was considered to be ntial because of the proximity of the slit to the photo-tiplier, which is of the Allen type.(4) In using this material the two tension springs, one disadvantage is that its oring power is not as great as that given by an ordinary ing steel; however, this is easily overcome by approaching quired slit width from the wider side.

he diagram indicates the small size of the slit and shows compactness. The size could be decreased by using inary spring steel for the springs if the vacuum require-nts are not too critical, whilst, if only small variations in lth are required, considerable further reduction in size uld be possible. The micrometer head could be fitted ernally to the spectrometer through a suitable type of uum seal, provided the slit is to remain stationary.

he author would like to acknowledge the contribution of . J. R. Budge, of the Physics Department workshop staff, o provided the skill and engineering knowledge required produce the slit, and to thank Dr. S. E. Williams for the erest shown by him and Professor C. J. B. Clews who made work possible.

he author, who is I.C.I.A.N.Z. Research Fellow, was in eipt of a University Research Grant when the design and nstruction of the slit were completed.

REFERENCES

KINGSTON, R. H. *Technical Report No.* 193, Research Laboratory of Electronics, Massachusetts Institute of Technology, 1951.

ROEMER, H., and OETJEN, R. A. *J. Opt. Soc. Amer.*, **36,** p. 47 (1946).

CHRISTENSEN, M. T. *J. Sci. Instrum.*, **30,** p. 70 (1953).

ALLEN, J. S. *Rev. Sci. Instrum.*, **18,** p. 739 (1947).

An automatic thermostat warming-up device

By M. W. JERVIS, M.Sc., A.M.I.E.E., Associated Electrical Industries Ltd., Aldermaston, Berks.

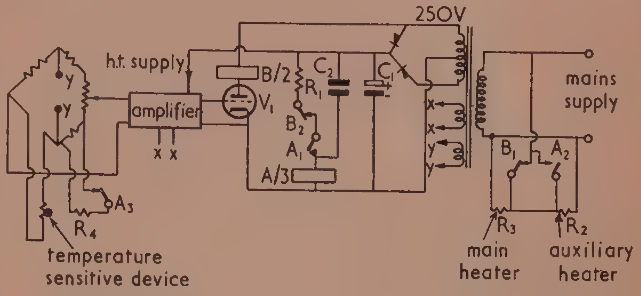
[*Note first received* 7 *May, and in final form* 27 *May*, 1954]

a typical arrangement for the temperature control of a ter bath which is not run continuously, it is convenient to ploy an auxiliary heater to raise the temperature quickly m room to operating temperature. Manual switching of s heater is inconvenient and often results in overshoot of nperature, and a separate thermostat set at a temperature t below that of the main thermostat is often inconvenient.

In a modification of the thermostat temperature controller scribed by Noltingk and Snelling,(1) the desired result has en achieved by the present author's arrangement shown in figure.

On switching on from cold, the reservoir capacitor C_1 is pidly charged and the rise in voltage charges C_2, the arging current operating the relay *A* which remains energized the current through R_1 and the hold-on contacts A_1. e auxiliary heater R_2 is switched on by the contacts A_2. e phase of the bridge supply voltage is chosen so that the lve V_1 is cut off when the temperature is low, the relay *B* not energized, and the main heater R_3 is switched on by the rmally closed contacts B_1. When the bath reaches operat- temperature, V_1 conducts, operates relay *B* and switches the main heater. It also opens the contacts B_2 and switches the auxiliary heater by de-energizing relay *A*. The bath nperature then falls until the relay switches on the main heater, but the auxiliary heater remains off and the thermostat operates normally. A similar circuit can be added to the thyraton relay arrangement(2) controlled by a mercury–toluene thermostat.

It was found that a 15 l. water bath could be conveniently kept at 28° C by a 100 W heater. With a 1·5 kW kettle element as auxiliary heater, the warm-up time from 15° C was ten minutes in contrast to several hours without it. With this heater, the water temperature overshot about 1° C, falling to the final value in another fifteen minutes. This overshoot can be prevented if the auxiliary heater is switched off at a temperature 1° below the final value. This can easily be achieved by the contacts A_3 which shunt a resistor R_4 across one arm of the bridge. This resistor is adjusted so that when the auxiliary heater is switched off, the main heater comes on after a few seconds. With this circuit, the bath temperature reaches its final value in fifteen minutes from switching on.



Automatic warming-up system applied to Noltingk and Snelling's thermostat(1)

(Suitable components: $R_1 = 47\,000\ \Omega$, $C_1 = 8\ \mu\text{F}$, $C_2 = 1\ \mu\text{F}$, Relays P.O. type 6250 Ω.)

The author is indebted to Dr. T. E. Allibone for permission to publish this note.

REFERENCES

(1) NOLTINGK, B. E., and SNELLING, M. A. *J. Sci. Instrum.*, **30,** p. 349 (1953).

(2) PFESTORF, G. K. M. *J. Sci. Instrum.*, **29,** p. 378 (1952).

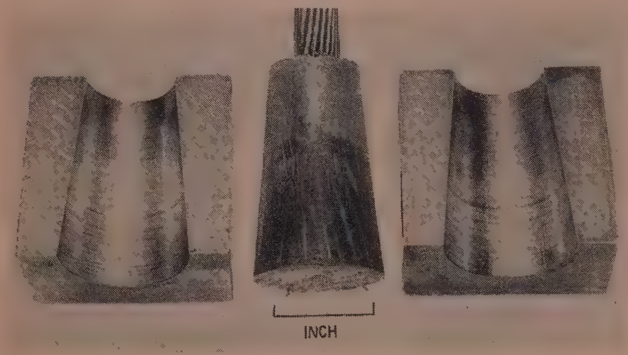
An effective method of gripping short specimens of wire strand for tensile tests

By the late F. D. HILLS, Ph.D., Johnson and Phillips Ltd., Charlton, London

[*Note received* 27 *May*, 1954]

In the tensile testing of the larger sizes of wire strand it is difficult to grip the specimen sufficiently firmly to hold the inner wires without crushing the outer ones. This difficulty cannot be overcome by sweating the ends of the strand solid by normal soldering methods since annealing of the wire would occur. It is usual, therefore, to employ long cumbersome samples in a large tensile machine with specially designed jaws.

The present note describes a simple technique involving setting the ends of the strand in truncated cones of cold setting Marco resin (a styrene-polyester copolymer manufactured by the Scott Bader Co. Ltd.) All the wires of the strand are securely held and short 18 in. specimens can be broken without premature failure being caused by crushing. The specimen is prepared using a split mould (see the figure) which is lightly waxed and placed in position round the end of the strand after the wires have been spread apart and thoroughly degreased with the usual solvents. A wide adhesive polyvinyl chloride tape is used to seal the side junctions and bottom of the mould, which is then filled with Marco resin which sets in about an hour. The specimen is then removed and inverted and the other end of the strand prepared similarly. Tapered split collets are used in the tensile machine to grip the resin cone ends.



Completed casting and split mould

This method was developed during an investigation of strand joints and has been used successfully to break over 200 specimens (with both aluminium and copper strand of 37 wires each 0·072 in. diameter). A $2\frac{1}{2}$ t capacity pendulum-type tensile machine (by W. and T. Avery Ltd.) was used and breaking loads of up to 5000 lb were encountered.

The author wishes to thank the Directors of Johnson and Phillips Ltd. for permission to publish this note, and the Chief Chemist, Mr. P. A. Raine, for every encouragement during the work.

A method of estimating distortion in cloud chamber tracks

By N. CUSACK, B.Sc., Ph.D., and P. STOTT, B.Sc.,
Birkbeck College, University of London

[*Note received* 5 *May*, 1954]

A method of investigating track distortion due to gas movements has been described by Wilson* and makes use of the straight tracks of energetic cosmic-ray particles. A method more suited to a horizontal chamber not designed for counter control was needed and the following procedure, which is simple and can be applied during the normal operation of the chamber, was adopted. Each photograph was taken by the light of two separate flashes, a timed interval apart. Track movements due to gas motion caused doubling of the track images, elongation of the background droplets and similar phenomena, and by measuring the displacement of tracks in the known time, the velocity of the gas currents producing distortion was estimated. The distance measurements were made on the film with a microscope and calibrated eyepiece scale.

If t_1, t_2 be the times of opening and closing of the window admitting electrons, and t_3, t_4 the times of the flashes, then t_1, t_2 measured from the end of the expansion were 3 and 25 ms and t_3, t_4 could be varied independently from 20 to several hundred ms.

The flash tubes were triggered in the usual way with induction coils, and t_3 and t_4 were controlled by the time constants of the grid circuits of two triodes. However, t flashing of a tube may be significantly later than the closi of the primary of its induction coil and therefore the ($t_4 -$ control was calibrated by detecting the radiation from t flashes themselves; the calibration apparatus was used f periodic checks throughout a run of photographs. T calibration apparatus consisted of a photocell, catho follower, Schmitt trigger and triggered pulse generator. T output of the latter operated a Chronotron (by Electron Instruments Ltd.) reading directly in milliseconds.

The results will be indicated very briefly because th will, no doubt, vary from chamber to chamber. The chamb used was 8 in. in diameter, nitrogen-filled and operated on every 1·5 min with an expansion ratio of 1·13. The ba was slightly cooled with running water but, apart from tha no elaborate methods of temperature stabilization we used. Only when $t_3 \geqslant 100$ ms and $t_4 - t_3 \geqslant 150$ ms cou definite doubling of tracks or parts of tracks be detected the vertical camera. Doubling gives a measure of the con ponent of gas velocity perpendicular to the track, and som times the actual direction of motion as well if one of t images—presumably the second one—is noticeably dark than the other. Motion was usually radial and the avera velocity deduced from 31 double images in a run of 1 pictures was 0·3 cm/s. Doubling represents the extren upper limit of track distortion, since it occurs only on small minority of tracks, almost all of which are near the ed of the chamber or near an irregularity in the wall whe there is a thin window, and it occurs only for very high valu of t_3 and t_4 such as would not be used in an actual experimen The velocity increased as t_3 increased and would therefore smaller during the time t_1 to t_3.

So many factors influence the thickness of a track imag that velocities cannot reasonably be obtained from trac which are not double. However, apparently good and th tracks occurring on photographs with $t_4 - t_3$ equal to 200 m or more enable upper limits to be put on the velocity con ponent perpendicular to the track. Such upper limits range from 0·12 to 0·25 cm/s.

The authors conclude that a reasonable figure to take f the gas displacement influencing a track photographed 100 m after formation would be 0·01 cm. This is comparable wit the example given by Wilson.

In some experiments it might be an advantage to take eve photograph by means of two separated flashes a known tim apart; it would then be possible to place an upper limit o the distortion of every track examined.

The authors are indebted to Mr. B. Zacharov for helpf discussions on the time measuring circuits.

---

* WILSON, J. G. *Principles of Cloud Chamber Technique* (London: Cambridge University Press, 1951).

The preparation of unbacked gold films of known thickness

By W. E. SPEAR, B.Sc., Ph.D., University College of
Leicester

[*Note first received* 29 *June, and in final form*
14 *September*, 1954]

In a number of research problems unsupported metalli films of accurately-known thickness are required. Beate gold and silver foils are commercially available down to thickness of about 2000 Å. However, these foils are unsui able in many cases as they show considerable non-uniformit in thickness and structure, and have a large number of pin holes. Unbacked aluminium films of the order of 1000 thickness have been obtained by evaporation on to a glas e coated with a water-soluble layer.(1) Beryllium films he same thickness and up to $1\frac{1}{2}$ in. in diameter have been pared by Bradner.(2) Hast(3,4) describes the production extremely thin beryllium and aluminium films for use in tron microscopy; these are prepared by evaporation on to ollodion film or a glycerol surface.

t first a method similar to that of Hast was tried for the paration of gold films, unsupported over an area of about n², using a somewhat thicker plastic base, but it was not nd possible to remove the base completely; moreover, the tended to curl up after the removal of the base, which de subsequent weighing and mounting extremely difficult. e following method, which overcomes this difficulty, has n used for the preparation of unbacked gold films down a thickness of about 400 Å, and of 1–2 cm² surface area. piece of aluminium foil (about 8000 Å thick) is cut to a ndard area and weighed with a sensitive torsion-balance. ch a foil is fairly robust and can be handled with comative ease. A layer of gold is then evaporated on to the minium in the usual way. It was found essential for the ccessful preparation of the films to work with a carefully tgassed vacuum system, so that the evolution of gas during aporation should be small. The composite foil is reweighed d mounted on the supporting frame in which it is subseently to be used. This is best done by applying a slight ear of Apiezon vacuum grease to the edge of the frame. the case of a 400 Å gold film the difference in weight will about one third of the weight of the aluminium base, so at the thickness of the gold can be obtained with accuracy. drop of 1/5 N solution of sodium hydroxide is placed on e centre of the aluminium backing and is carefully spread t to cover 1–2 cm². After a few minutes the aluminium s dissolved and the remaining liquid is sucked back into e pipette from the edge of the dissolved area. This operation facilitated by mounting the pipette in the tube of an old croscope. To wash the film the frame is held vertically, d drops of distilled water are applied to the upper edge of e frame with a camel-hair brush and removed at the lower ge with blotting-paper.

It is possible to use beaten aluminium film as the base, ovided a region of faultless surface is selected, but it is eferable to produce the foil by evaporation. It has been und most convenient to evaporate the aluminium on to lished copper foil (0·0003 in.), mount, and dip into conntrated nitric acid. The copper dissolves instantly and ves a good aluminium film, which is washed and cut to e required size.

It should be possible to apply the method described to uttered platinum films and films of other heavy metals ich are not attacked by sodium hydroxide.

REFERENCES

Carpenter, F. E., and Curcio, J. A. *Rev. Sci. Instrum.*, **21**, p. 675 (1950).
Bradner, H. *Rev. Sci. Instrum.*, **19**, p. 662 (1948).
Hast, N. *Nature* [*London*], **159**, p. 370 (1947).
Hast, N. *Nature* [*London*], **162**, p. 892 (1947).

A multi-range laboratory flowmeter

By K. H. Todhunter, M.Sc.(Tech.), and B. Wolstenholme, Research Department, Simon-Carves Ltd., Cheadle Heath, Stockport

[*Note received* 9 *June*, 1954]

the laboratory, fluid velocities are usually measured by pillary flowmeters, each calibrated and suited to a particular range of flows. Where a wide range of flows has to be measured in the same experiment, capillaries and manometer fluid may have to be exchanged and this is often a nuisance and time-consuming. These difficulties may be avoided by the following flowmeter arrangement, which has proved quite satisfactory and easy to manipulate. The capillary tubing is simply replaced by a glass cock of suitable dimensions, the pressure drop across which varies with the available free cross-sectional area for flow, i.e. with the position of the barrel bore relative to the bore of the tube carrying the fluid. By selecting different positions of the cock, therefore, a multi-range flowmeter is obtained.

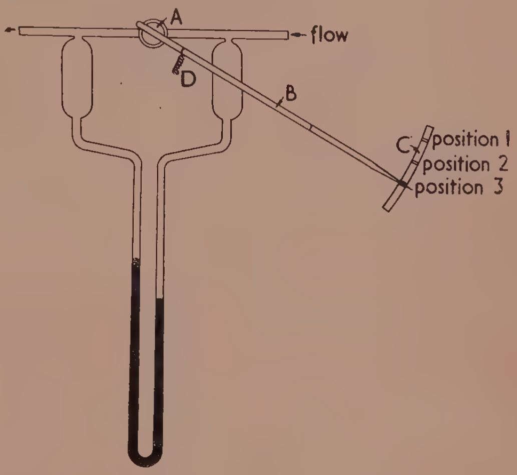


Fig. 1. Flowmeter

Each setting of the cock corresponds to a specific flow range, and it is, therefore, highly important that these settings are easily and accurately located. This is achieved by fusing to the glass cock *A* (Fig. 1) an extension arm *B* which moves over a fixed brass sector *C* in which are cut a series of locating slots corresponding to the different flow ranges. A length of arm of 8 in. was used in the present set-up.

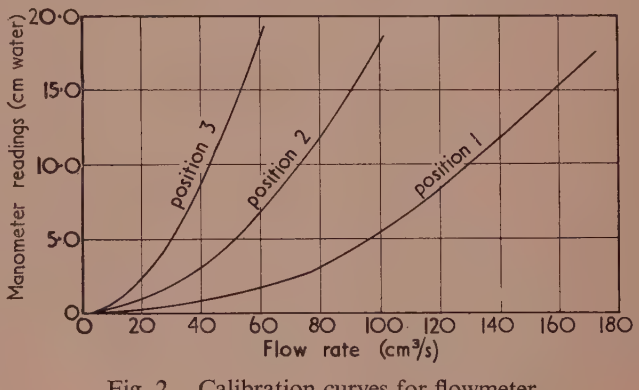


Fig. 2. Calibration curves for flowmeter

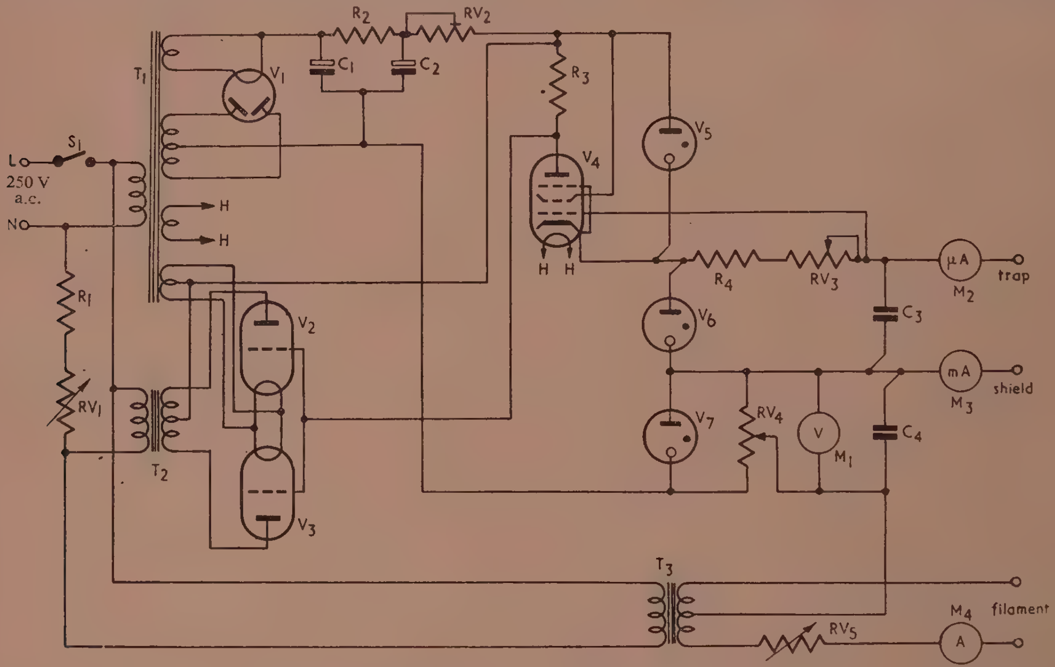
To restrain the barrel from being displaced out of the cock, a tension spring *D* was fixed between the arm *B*, close to *A*, and the board on which the meter was mounted. Alternatively, commercially-available spring-loaded cocks could be used for this purpose.

Calibration curves for a three-range flowmeter (Fig. 2) were quite smooth and reproducible; readings for the same flow rate varied by less than 1% even if the cock barrel were removed, cleaned and replaced.

Correspondence

A trap-current controlled emission regulator for a mass spectrometer ion-source

In the widely used Nier-type emission regulator,(1) the temperature of the filament in a mass spectrometer source is controlled to maintain constant its total emission. However, it has been argued(2) that in certain cases, e.g., if leakage currents exist within the source assembly, more satisfactory operation might be obtained if the current reaching the electron trap were the quantity to be held constant by control of filament temperature.



Circuit of a regulator for a mass spectrometer ion-source

$R_1 = 150\ \Omega$, 50 W
$R_2 = 1\ k\Omega$, 20 W
$R_3 = 0{\cdot}25\ M\Omega$, 1 W
$R_4 = 0{\cdot}1\ M\Omega$, 1 W

$RV_1 = 250\ \Omega$, 50 W power rheostat
$RV_2 = 5\ k\Omega$, 20 W
$RV_3 = 0{\cdot}5\ M\Omega$ linear
$RV_4 = 10\ k\Omega$, w.w.
$RV_5 = 2{\cdot}5\ \Omega$, 50 W power rheostat

C_1, C_2 = 16 μF, 625 P.V. electrolytic
$C_3 = 0{\cdot}5$ μF, 400 V
$C_4 = 1{\cdot}0$ μF, 400 V

M_1 = 0–150 V, 1 kΩ/V
M_2 = 0–50 μA
M_3 = 0–1 mA
M_4 = 0–5 A, a.c.

T_1 Primary = 250 V
Secondary = 350–0–350 V, 50 mA, 5 V, 3 A, 6·3 V, 3 A
All insulated to 2 kV

T_2 Primary = 250 V
Secondary = 400–0–400 V, 80 mA
Insulated to 2 kV

T_3 Primary = 250 V
Secondary to suit filament

V_1 = 5Y3G (CV.1854)
V_2, V_3 = 6A3 (CV.730)
V_4 = 6SJ7GT (CV. 592)
V_5, V_6, V_7 = VR105 (CV.686)

During the course of work being carried out in the Department of Physics at the University of Western Australia, on the mass spectrometric determination of the stable carbon isotope ratios, the standard type emission regulator employed did not appear to be functioning satisfactorily. Accordingly, it was decided to modify the circuit for trap current control. The details of what appears to be a highly successful trap current controlled regulator have already been published by Solomon and Caton,(3) but in our case it was felt that a simple modification of the existing unit was all that was justified.

The removal and rewiring of a few resistors and potentiometers resulted in the accompanying circuit. The trap current flows through RV_3 and R_4, and the resultant potential difference is applied between grid and cathode of V_4, which in turn controls the bias to the pair of power triodes, V_2 and V_3. The load imposed by the anode current of these valv on T_2 determines the voltage drop developed across the pow resistors R_1 and RV_1 in the mains supply, and consequent the voltage fed to the source filament transformer T_3. Th any increase in trap current tends to cause a compensati decrease in filament supply voltage, and *vice versa.*

The operating region of V_4 under these conditions appea to be centred about a bias of about 6·0 V, so that, with t values of RV_3 and R_4 indicated, trap currents between and 60 μA can be accommodated. RV_3 should be calibrat in terms of the currents which will give a 6·0 V drop acro the pair, and in operation, set to the particular trap curre required. RV_1 and RV_5 should then be adjusted until th trap current is indeed obtained. It is important that R should be fully in circuit when the instrument is first switche on, otherwise the full voltage, which is applied to the mas spectrometer filament until the control valves warm up, ma cause damage. A series connexion of the primary winding of transformers T_2 and T_3 would overcome this disadvantag but such a change would add complexity to the circuit as a additional phase reversal would then be required in th amplifying stage.

With the trap current set at 28 μA, a change of ±5 V the 250 V mains supply was found to produce a 0·1 change in trap current. During a test run of one hour, th trap current increased from 28·0 to 28·6 μA in a twelv minute settling-down period after switching on (+11% p ur); in the next twenty-four minutes it fell to 28·2 μA 3·6% per hour); and in the final twenty-four minutes it urned to 28·0 μA (−2% per hour).

ysics Department,
iiversity of Western Australia.

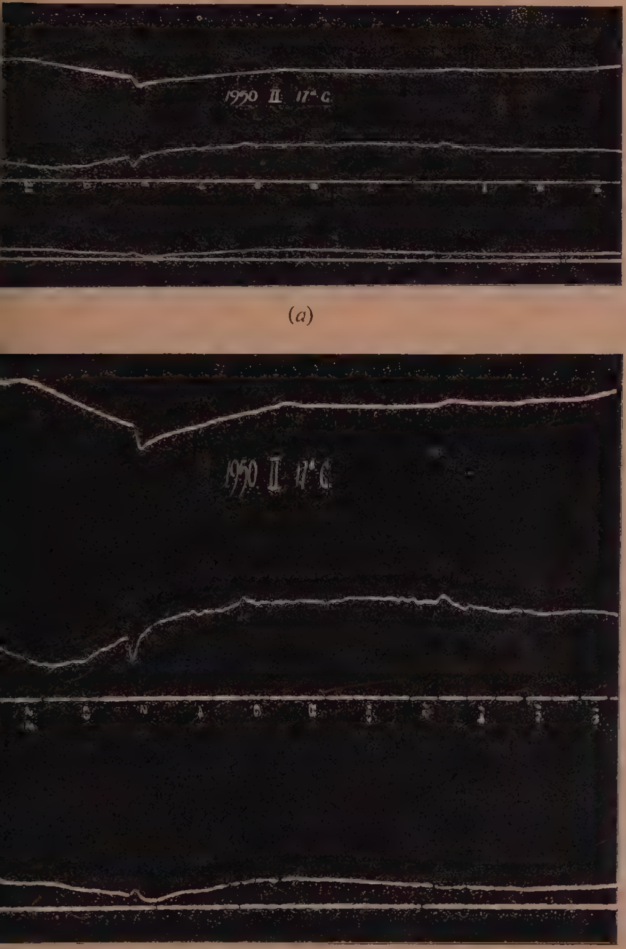
D. Greenhalgh
P. M. Jeffery

REFERENCES

Nier, A. O. *Rev. Sci. Instrum.*, **18**, p. 398 (1947).
Barnard, G. P. *Modern Mass Spectrometry*, p. 64 (London: The Institute of Physics, 1953).
Solomon, A. K., and Caton, D. C. *Rev. Sci. Instrum.*, **12**, p. 757 (1952).

iotographic enlargement and reduction in one dimension only

sometimes happens that records obtained with recording eters are not as suitable for purposes of illustration as for eir original object. Magnetograms, for example, have an tended time scale whose length is related to the accuracy th which it is desired to time events. But this leads to oportions which are unsuitable for illustrations. The need alter the proportions of illustrations for published papers equently arises and is usually met by redrawing. But in e case of complicated records this may not be practicable, and to meet this situation a photographic method of altering proportions has been devised.



(a)

(b)

Fig. 1. (*a*) Normal magnetogram; (*b*) magnetogram with proportions altered

Fig. 1(*a*) shows a magnetogram which in the original is 19 in. long, thus necessitating a reduction of about 1 : 5 for publication. Fig. 1(*b*) shows the result of altering the proportions photographically so that the ordinates are reduced by 1 : 2 only.

The procedure used was to place the magnetogram flat on the floor with its long axis running towards a stand on which a camera was mounted a few feet above ground level (Fig. 2). A photograph was taken at an oblique angle, thus obtaining foreshortening in the desired sense. The photograph was naturally wedge-shaped. To remove the wedge distortion, the print was placed on the floor in the position originally occupied by the magnetogram, with the narrow end towards the camera which had been left undisturbed. This step completely removed the distortion and gave the result shown in Fig. 1(*b*). By making the final copy rectangular one exactly compensates the distortions present in the intermediate step. For the final copy is the result of two consecutive projective transformations of the original and is therefore itself a projective transformation of the original. Now since, by a theorem from projective geometry, four points may in general be assigned arbitrary transforms, it follows that if the four corners of a rectangular original project into the four corners of a rectangle in the final copy, then the rest of the transformation is fixed. But the orthogonal projection (with magnification) is one such projective transformation; therefore it is the only one.

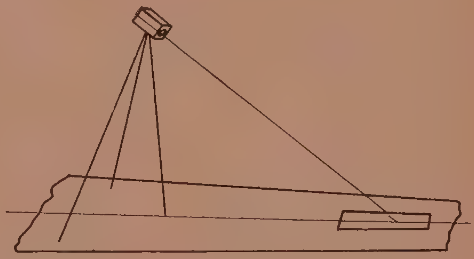


Fig. 2. Arrangement of camera and magnetogram

It was also found possible to remove the wedge distortion without rephotographing, by printing the original negative obliquely: tilting either the enlarger table or the projector.

Difficulties over depth of focus were easily avoided by using good illumination and narrow apertures. Special cameras with tilting fronts, such as are used for photographing tall buildings, might suggest themselves as a means of obtaining sharp focus over the whole field being copied, but consideration would show that the desired foreshortening would thereby be eliminated.

It is easy to calculate the precise amount of compression obtainable with a given angle of incidence, length of record and distance from camera. A good approximation to the compression is $\cos^2 i$, where i is the angle of incidence.

Division of Radiophysics,
Commonwealth Scientific and
Industrial Research Organization,
Sydney, Australia.

R. N. Bracewell*

---

* Now at Berkeley Astronomical Department, University of California.

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved products. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

Electronic motor controller. Servomex Controls Ltd., Crowborough Hill, Jarvis Brook, Sussex.

The type MC. 31 controller comprises a d.c. motor of about 0·1 b.h.p. joined by a flexible cable to the control unit. The motor armature is supplied with a constant direct current of 5 A. The back e.m.f. has virtually no effect on the armature current, so that to a first approximation the maximum rated torque is available over the whole range of speeds. Mechanically coupled to the motor is a d.c. tachometer designed to give an output voltage accurately proportional to the motor speed. The output is metered and is also compared with an electronically stabilized reference voltage. The difference, or error, voltage is amplified and applied to the motor field coils. The result is that if the speed error is only 6 rev/min, the motor develops full torque to accelerate to the correct speed. Consequently, over the rated range of torques, the speed error can never exceed 6 rev/min for more than a few milliseconds and is usually much less than this. It is claimed that, owing to the special design of the motor with abnormally low moment of inertia, a suddenly applied load is usually taken up in about $\frac{1}{50}$ sec. The motor has a stalled torque of 21 oz. in. and its speed can be smoothly varied over the range 0–6000 rev/min in either direction. The speed is stated to be constant to ±6 rev/min from no-load to full rated torque, and for changes of ±10% in the supply voltage and frequency.

Pipette control. Shandon Scientific Company, 6 Cromwell Place, London, S.W.7.

A pipette control, known as the Pumpett, has been developed to replace the method of suction by mouth. The device consists of an acid resistant moulded plastic body surmounted by a surgical-grade rubber operating bulb. The body houses rubber-lined chuck jaws which grip the pipette, a coarse air-control valve and a micro-control screw valve. The chuck jaws are controlled by a fingerplate and the coarse air-control valve is a plunger-type valve with an air vent in its outer end. Either of these controls may be operated with the index finger whilst the body is held in the hand, and the thumb is used to operate the bulb and the screw control valve. Filling the pipette is performed by compressing and then releasing the rubber bulb; the rate of filling is controlled by the coarse and fine valves. Emptying of precise quantities can also be controlled accurately by the coarse- and fine control valves. The makers claim that even in the case of very fine micro-pipettes with a content of a few thousandths of a millilitre positive and accurate control is possible.

Pipette control

Germanium junction photocells and power rectifiers. Standard Telephones and Cables Ltd., Warwick Road, Boreham Wood, Herts.

These devices are based on the use of a germanium *p–n* junction, which is capable of carrying much greater power than a point contact. The photocell consists of such a junction which, if suitably biased (from 1 to 50 V), passes a saturation current which is practically independent of the applied voltage When the junction is illuminated the current is increased by an amount proportional to the illumination. The photo cell therefore has a characteristic similar to those of vacuum and gas-filled photocells, as distinct from photo-voltaic cells It is of very small size ($\frac{7}{32}$ in. diameter × $\frac{11}{32}$ in. long plus $1\frac{1}{2}$ in. for the connecting lead) and has an effective active area of only 1·5 mm × 0·1 mm. It has much greater sensitivity than a gas-filled cell (30 mA per lumen for tungsten filament light at a colour temperature of 2500° K). The small germanium element is mounted in a cylindrical metal case having a glass window at one end to admit light and a connecting wire at the opposite end, which is joined to the germanium element by a glass-metal seal. The element is thus hermetically sealed, ensuring a long life with stable characteristics. Owing to the small working area of the germanium junction, this type of photocell is insensitive to ambient light, and the incident light to be measured should be focused on as small an area as possible.

The power rectifiers are, like the photocell, of small size One type (R50A) measures $1\frac{1}{32}$ in. diameter × $\frac{1}{4}$ in. plus $1\frac{1}{2}$ in. for the connecting lead. It is rated to pass a mean forward current of 100 mA and to withstand an inverse voltage of 140 V. The even smaller type R50B measures $\frac{7}{32}$ in. diameter × $\frac{11}{32}$ in. long plus 3 in. for the connecting leads. It is rated to pass a mean forward current of 30 mA and to withstand a peak inverse voltage of 165 V.

Pulse height analyser. Sunvic Controls Ltd., 10 Essex Street London, W.C.2.

An electronic instrument based on the design of Hutchison and Scarrott* is now available for the analysis of complex pulse amplitude spectra. The instrument sorts the incoming pulses into groups according to their voltage amplitude The number of groups can be either 60, 80 or 120. The maximum mean counting rate is 1600 pulses/s. The maximum storage capacity is 1200 binary digits, and these are divided equally between the various channels. The instrument therefore provides 120 channels each capable of recording 1024 pulses, 80 channels of up to more than 3×10^4 pulses

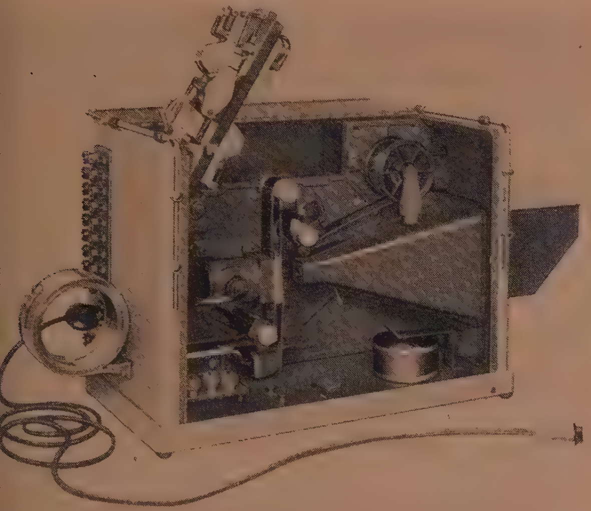
---

* Hutchison, G. W., and Scarrott, G. G. *Phil. Mag.*, 42 p. 792 (1951).

60 channels of more than 10^6 pulses each. The display is sented on the screen of a cathode-ray tube in the form of raster of vertical lines, one line for each channel. The unt in each channel is represented on a binary scale by an ay of brightened dots. The least significant figure in each annel appears at the bottom of the line, and hence the lse spectrum is approximately plotted on a logarithmic scale the dots representing the most significant figure in each annel. The instrument incorporates a pulse generator for ibration.

lus oscillograph. Parkinson and Cowan Instruments, 7–17 Fitzalan Street, Kennington Road, London, S.E.11.

e type OSL 81 oscillograph, illustrated in the figure, is able inscribe simultaneously records of eight separate electrical antities on a specially prepared 35 mm film. The basis the instrument is a measuring element of the moving- n type with torsion bar suspension. A triangular light oy stylus arm is secured at its base to the moving-iron tion. Mounted at the tip of the arm is a stylus of hard



Side view of oscillograph open, showing the measuring elements raised, the film magazine at the rear and the start/stop push-button in the foreground

aterial which inscribes the record on the film. Provision is ade for the adjustment of stylus pressure and stylus arm nement. The power consumption of an element is 0·8 W r a deviation of 0·5 mm. The standard element range ailable extends from 75 V 10 mA to 0·75 V 1 A. The ements are interchangeable, and any combination of ailable types may be fitted in one instrument. A marker ement is mounted on the same framework as the measuring ement, and consists of a non-polarized electromagnet.

The recording film has a backing of non-inflammable llulose acetate of standard 35 mm width and with standard rforations. Deposited on the film is a thin layer of black rnish upon which the trace is inscribed. The varnish layer sufficiently thin for the film to be handled without un- asonable precaution and is soft enough to reduce stylus ction to a minimum. For permanent storage, the traced m may be fixed by spraying with diluted cellulose varnish.

The trace produced on the film has a uniform width of 01 mm with a maximum amplitude of 1 mm. The record n be viewed immediately after recording by employing the ilt-in enlarger, which projects the record on to a ground-glass screen with a magnification of ×5. Further useful magnification up to ×50 could be used.

When the film has passed under the styli, it eventually passes through a slot at the rear of the instrument into a magazine. During examination of the film, it is fed back into the oscillograph. A film cutter is built into the magazine. A spool of special film is about 24 m long, giving a running time of 40 min at the slowest film speed of 1 cm/s. Higher speeds of 2, 4 or 8 cm/s are obtained by merely changing the position of the mains input plug.

Precision potentiometers. Ohmag, Neuchâtel, Switzerland.

The Ohmag series of low friction potentiometers is marketed in this country by J. Langham Thompson Ltd., Bushey Heath, Herts. They are intended for use in telemetering, servomechanisms and computors, and are characterized by low friction and high accuracy. The resistance range available is 100 Ω to 100 kΩ. Standard models are guaranteed to within ±3% of the nominal resistance, but special models can be produced correct to ±0·2%. The linearity is normally within ±0·5%, but this tolerance can be reduced to ±0·15%. The shaft is free to rotate through 360°. The resistance winding can be either continuous through 360° and closed on itself, or can be limited to 355°. A variety of models is available with fixed taps at various points and with either single sliders or two sliders 180° apart. For example, one model having a winding closed on itself is provided with four fixed taps 90° apart and two sliders 180° apart with separate external connexion. The shaft is mounted on miniature ball bearings, has a low starting torque (about 0·004 oz. in.) and is capable of running at speeds up to 3000 rev/min. The small size of the potentiometers (approximately 1 in. diameter × 1½ in. long) enables them to withstand large accelerations (15 *g* perpendicular to the axis and 50 *g* along the axis). The makers claim that these mechanical features are combined with an electrical resolution between 32′ per turn and 11′ 30″ per turn according to the resistance range. Potentiometer sections may be stacked and supplied as ganged models to which similar characteristics apply.

Of basically similar construction to the potentiometers is a pulse generator transmitting from 1 to 240 impulses per rotation. This has a stainless steel stator and platinum-iridium slider. A commutator is also available capable of switching on or off five different circuits.

Precision vernier potentiometer. Croydon Precision Instrument Co., 116 Windmill Road, Croydon, Surrey.

This potentiometer is a two-range instrument. On its principal range, it covers the interval 0–1·9 V in steps of 10 μV. A range plug changes this to 0–0·19 V in steps of 1 μV. The instrument has three main dials. The first has 18 steps of 0·1 V, the second is a vernier on the first and has 100 steps of 0·001 V and the third has 101 steps of 10 μV and reads from −10 μV to +1 mV. Standardization is effected by balancing the standard cell against an auxiliary divider calibrated from 1·018 00 V to 1·019 00 V by steps of 50 μV. The adjustment is made by a five-decade rheostat, and is independent of the range setting. A special feature claimed for this instrument is that all terminals and studs are of copper, the studs being tipped with a precious metal alloy to minimize thermoelectric e.m.f.'s. Bare manganin (Telcuman) wire of the same gauge is used throughout the whole potential divider, thus reducing the temperature coefficient of the potentiometer to a minimum. The accuracy claimed is of the order of 1 part in 10^5 of the 1 V setting.

Notes and comments

Craftsmanship and draughtsmanship competition for apprentices and learners

In order to encourage the production of high-grade work amongst apprentices The Physical Society will again hold in 1955 its annual competition for those under 22 years of age. The classes under which work may be offered are: (i) Scientific instruments and components: [(*a*) junior grade; (*b*) senior grade.] (ii) Tools and gauges: [(*a*) Junior grade; (*b*) senior grade.] (iii) Optical components and systems. (iv) Blown-glass and silica ware. (*v*) Sections of instruments, functional scale models of scientific interest and patterns. (vi) Draughtsmanship: [(*a*) junior grade; (*b*) senior grade.] (vii) Silvanus P. Thompson Prize (i.e. draughtsmanship and craftsmanship combined: the two entries required may be entered also in the appropriate individual classes). Electrical work will generally be entered under "Scientific instruments and components," but radio and electronic chassis assemblies are excluded from the competition. Model ships, engines, cars, etc., are also excluded. In classes where a junior and senior grade is indicated the division will be made according to the age of the competitor on 31 March, 1955. Junior competitors must be 18 years of age and under, senior competitors must be over 18 but under 22 years of age.

Entries will be accepted from employees of firms, research associations and institutions which have exhibited at The Physical Society's Annual Exhibition at least once during the last three years, from employees in the workshops or drawing offices of educational establishments and from students attending recognized workshops or machine-drawing courses at technical colleges or technical schools. The competition is open equally to both sexes. Prizes will be awarded in each class, but it is generally agreed that the honour and status accruing to the prize winner and to his employer and teacher is of more importance than the money involved.

The entries submitted will be displayed at The Physical Society's Annual Exhibition of Scientific Instruments and Apparatus to be held during Spring 1955. A selection of th entries will be transferred to the Science Museum for a sho period following the exhibition. Applications should b made to the Secretary, The Physical Society, 1 Lowthe Gardens, Prince Consort Road, London, S.W.7. The las date for receiving entry forms is 21 February, 1955.

A further volume of laboratory and workshop notes

A third selection of laboratory and workshop notes an cognate articles, reprinted from this *Journal* has just bee published, with the title *Laboratory and Workshop Note* 1950–1952 by Edward Arnold (Publishers) Ltd. at 30*s*. net Once again through the courtesy of the authors, the royaltie from the sale of this volume will be placed to the credit o The Institute of Physics' Benevolent Fund.

The new collection is divided into the following sections Mechanical design; Laboratory tools, methods and hints Optical and thermal devices and techniques and infra-re spectrometry; Devices for liquids and gases; Vacuum device and techniques; Electrical devices and techniques.

One reviewer referred to the previous volume as "a catalogue of ingenuity" and this might equally be said of thi new selection. Indeed it was because of the success of th first two volumes that the Board of The Institute of Physic decided to publish further volumes from time to time i order to assist laboratory workers, and at the same time, t help its Benevolent Fund.

For these excellent reasons, we invite our readers at hom and oversea to order a copy of this new volume, if indee they have not already done so.

Erratum

In the paper entitled *A method for constructing direc reading thermistor thermometers* by J. A. McLean which was published on p. 455 of the December 1954 issue of this *Journal*, there is an error in Fig. 2. The fourth (right hand) switch terminal of S_{1a} should be shown disconnected.

British Journal of Applied Physics

Contents of the January issue

SPECIAL ARTICLE

Some researches into the electrical conduction and breakdown of liquid dielectrics. By K. A. Macfadyen.

ORIGINAL CONTRIBUTIONS

Thulium 170 for industrial radiography. By R. Halmshaw.
A direct method of phase measurement on the cathode-ray tube. By D. Karo.
The calculation of voltage surges in a Van de Graaff generator. By B. Millar.
The calculation of heat flow through disks and its application to conductivity measurements. By J. C. Jaeger and A. Beck.
A method of identifying double-flash exposures. By N. Dombrowski.
Heat transfer through oxide-cathode materials. By A. E. Pengelly.
The rubber membrane and the solution of Laplace's equation. By W. Fulop.
The preparation of uniform plastic films. By R. S. M. Revell and A. W. Agar.
On the representation of rheological results with special reference to creep and relaxation. By P. Feltham.
Comparison of radioactivities by the use of X-ray film. By A. N. Davenport and G. W. W. Stevens.
The laminar flow of suspensions in tubes. By T. V. Starkey.

NOTES AND NEWS

New books

Notes and comments

Journal of Scientific Instruments

Original contributions accepted for publication in future issues of this Journal

The stability of the calibration of liquid sample Geiger–Müller counter tubes, with special reference to their use in automatic counting equipment. By N. Veall, A. E. Lowe and R. E. Whyard.
A reflexion electron microscope. By V. E. Cosslett and D. Jones.
A logarithmic photocell circuit. By V. H. Attree.
A tuned detector-amplifier for power-frequency measurements. By W. K. Clothier and W. E. Smith.
Apparatus for the measurement of the lifetime of phosphorescence phenomena. By A. van Roggen and R. A. Vroom.
A computing microphotometer for cell analysis. By S. Bourghardt, H. Hydén and B. Nyquist.
An instrument for the formation of visual images of ionizing radiations. By W. V. Mayneord, H. D. Evans and S. P. Newbery.
Errors of friction wheel integrators. By J. L. G. Michel.
A driving unit for a "time-lapse" ciné camera. By A. F. Hughes and W. R. Hughes.
An electronic phase shift tube for microwave frequencies. By D. H. Pringle.
A sensitive wave-front tilter. By M. De.
A compact monochromator employing rhombic constant deviation prisms. By J. W. Gates and S. P. Middleton.

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principles, construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Square, London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation of contributions.* (Price 2*s*. 6*d*. including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon application from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, London, E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within 60 days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of address or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £4 per volume ($11.50 U.S.A.), including index (post paid) payable in advance. Single parts, so far as available, may be purchased at 8*s*. each ($1.15 U.S.A.), post paid, cash with order. Orders should be sent to The Institute of Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

A logarithmic photocell circuit

By V. H. ATTREE, B.Sc.(Eng.),* Fluid Motion Laboratory, University of Manchester

[*Paper received* 23 *August*, 1954]

The circuit employs two valves and has a useful dynamic range of approximately three decades. Valve tolerances are accommodated by a simple setting procedure and the output is indicated on a robust meter. The circuit may be used either as a logarithmic photometer or, in conjunction with a light source, as a densitometer.

is often convenient to have a photocell circuit which will e an output reading proportional to the logarithm of the otocurrent. Such a device may be used to measure either ht intensity or photographic transmission density. The cuits described in the literature fall into two broad types; stly those which measure light intensity directly on a garithmic scale, and secondly those in which the reading obtained from the setting of a neutral-density wedge in the tical path. The direct-reading type may depend on the in characteristics of a photomultiplier with a variable node voltage,(1–3) on the curvature of a variable mu lve,(4) or on the retarded field characteristic of a triode.(5, 6) e self-balancing wedge instrument(7–10) is inherently more curate, as it gives a null balance, but it has the disadvantage at it is more complex and the photocell cannot be used at distance from the main instrument. The present circuit es the retarded field method which results in a simple ctronic unit and permits the photocell to be run at the end a long lead.

THE LOGARITHMIC CIRCUIT

Although the retarded field technique for obtaining a garithmic response is well known(5, 6, 11–14) most published cuits are either critically dependent on valve tolerances and ater voltage or are unduly troublesome to set up. The esent circuit avoids some of these difficulties by using a lanced arrangement with two controls only; one for the o, and the other for the slope of the log characteristic.

The most satisfactory arrangement for the first stage pears to be a type 12AU7 triode section run as shown in g. 1. The shape of the log characteristic at low inputs is inly determined by the cathode resistance while the permance at high inputs depends on the anode resistance. A al of twelve type 12AU7 valves were measured in the circuit and ten of these gave good logarithmic action over a range of at least three decades. The characteristics of a typical valve are shown in Fig. 2 and the limits for the ten satisfactory valves are shown by the dotted lines. The two unsuitable valves both had large grid currents under normal operating conditions, possibly due to excessive gas. For a typical valve the anode current i_a at a grid current of i_g is given by:

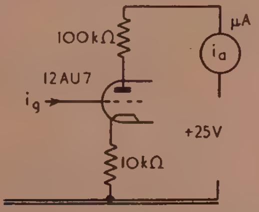


Fig. 1. Logarithmic amplifier

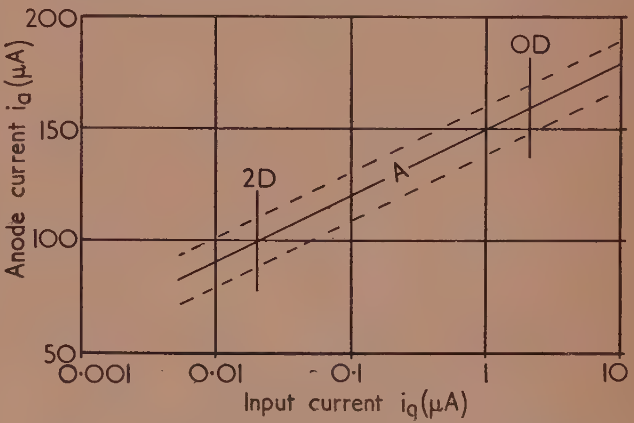


Fig. 2. Characteristics of a type 12AU7 logarithmic amplifier

Curve A, typical valve (limits shown dotted).

$$i_a = 150 + 30 \log_{10} i_g$$

The anode voltage V_a, with a 100 kΩ load and a 25 V supply thus becomes

$$V_a = 10 - 3{\cdot}0 \log_{10} i_g$$

where all currents are expressed in microamperes. In the complete instrument valve differences are accommodated by providing independent adjustment for both the constant term and the gradient term in the equation for the output voltage of the log stage.

The photocell is a Cintel type VA16 (by Cinema-Television Ltd.) and in order to ensure adequate saturation of the anode current it is run from a 150 V supply. The cell dark current is 0·001 µA at 20° C and normal operation is in the range 0·005 to 5 µA. Over this range the relation between light intensity and photocurrent is linear to within 5% (i.e. 0·02*D*) and fatigue effects are negligible. The accuracy of the complete instrument is mainly determined by the performance of the log stage and there appears little to be gained by using a special photometric cell.

---

* Now at Manchester College of Technology.

CIRCUIT DESCRIPTION

The complete circuit is shown in Fig. 3. The triode section V_{1a} provides the logarithmic action while V_{1b} gives zero setting and heater voltage compensation. Only a small current change is available at V_{1a} anode and a d.c. amplifier must be used in order to drive a robust meter. This amplifier must have precisely linear amplification as a small error occurring at a point subsequent to the logarithmic stage represents a considerable change in the indicated light intensity. The necessary linearity is obtained by using large degenerative cathode resistors, R_{14} and R_{16} in V_{2a} and V_{2b}, and by restricting the anode excursion to a small fraction of the h.t. supply voltage. The balanced arrangement provides a useful degree of compensation for mains voltage variations as the anode currents in V_{2a} and V_{2b} are equally affected by heater voltage changes. The meter has a 500 μA movement with the zero offset so that the pointer deflexion corresponds to 125–0–375 μA. The meter scale is graduated for a range of three decades in units of logarithmic transmission density D. The graduation starts at 2·5D (62·5 μA) and finishes at −0·5D (312·5 μA). The two calibration points are at 2·0D (0 μA) and 0D (250 μA).

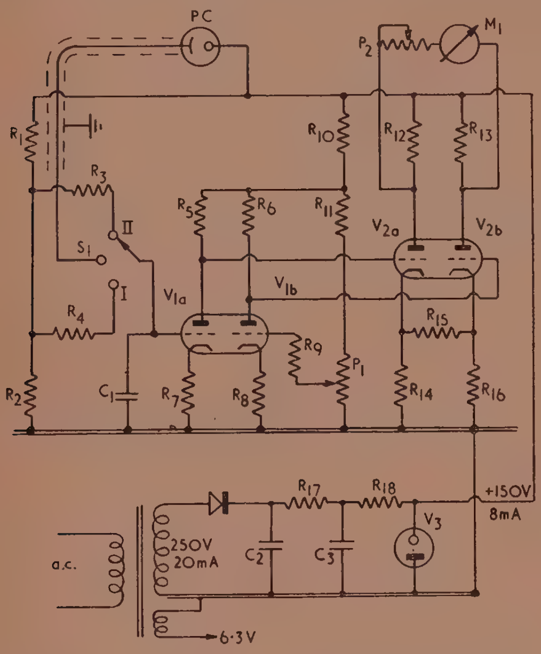


Fig. 3. Circuit diagram of logarithmic photocell

R_1 = 150 kΩ
R_2 = 100 kΩ
R_3 = 1/100 R4 (approximately 30MΩ)
R_4 = 3000 MΩ ± 20%
R_5, R_6 = 100 kΩ
R_7, R_8 = 10 kΩ
R_9 = 30 MΩ
R_{10} = 47 kΩ
R_{11} = 10 kΩ
R_{12}, R_{13} = 22 kΩ
R_{14} = 6·8 kΩ
R_{15} = 10 kΩ
R_{16}, R_{17} = 6·8 kΩ
R_{18} = 1 kΩ

P_1 = 1 kΩ (set 2·0D)
P_2 = 50 kΩ (set 0D)

C_1 = 0·001 μF
C_2 = 8 μF
C_3 = 16 μF
PC = VA 16 photocell

V_1, V_2 = 12AU7 (CV 491)
V_3 = 150B2 (CV 2225)
M_1 = meter
S_1 = 1-pole 3-way ceramic wafer switch

CALIBRATION

The three-position switch S_1 enables the logarithmic stage and subsequent d.c. amplifier to be set up independently of the photocell. The setting procedure involves two adjustments: the first of these corrects the zero of the logarithmic amplifier, and the second controls the effective slope of its characteristic. A reading of 2D on the meter is obtained by adjusting the potentiometer P_1 with S_1 at position I. A reading of 0D is then obtained by adjusting P_2 with S_1 at position II. The corresponding calibration currents are 0·02 μA (2D) and 2·0 μA (0D) as indicated in Fig. 2. In normal use S_1 is, of course, in mid-position to bring the photocell into circuit. The advantage of this particular method of setting-up is that adjustment of P_2 does not change the setting of P_1.

RESPONSE TIME

In order to ensure that the instrument reads correctly when working with a fluctuating light source it is necessary that the response time at the grid circuit of the log stage should be at least as long as the deflexion time of the meter. A sufficiently long response time at the input grid is particularly important if the instrument is calibrated with a rotating sector attenuator. For a given cathode temperature in V_{1a} the time constant is proportional to C/i where C is the capacitance from grid to earth and i is the photocurrent. Thus C must be large enough to give adequate integration at high photocurrents where C/i is relatively small. The value of C is not made larger than is strictly necessary as this would result in an unduly sluggish response at low photocurrents where the time-constant is much longer. Sufficient integration is obtained by the 0·001 μF plastic film capacitor C_1.

PERFORMANCE

The overall calibration of the instrument has been checked against a set of neutral density filters and also by a rotating sector attenuator. Light intensities are correct to 0·05D and individual readings can be repeated to 0·02D. A 10% change in the mains voltage alters the reading by approximately 0·02D. The instrument has been used for the measurement of photographic transmission density and for development work on a graded-filter Schlieren system.

REFERENCES

(1) Sweet, M. H. *Electronics*, **19** (11), p. 105 (1946).
(2) Plymale, W. S. *Electronics*, **26** (3), p. 143 (1953).
(3) Laurence, D. J. R. *J. Sci. Instrum.*, **31**, p. 137 (1954).
(4) Alder, K. F. *J. Sci. Instrum.*, **25**, p. 300 (1948).
(5) Hardy, A. C. *J. Opt. Soc. Amer.*, **18**, p. 96 (1929).
(6) Tait, R. I., and Chalklin, F. C. *J. Sci. Instrum.*, **30** p. 268 (1953).
(7) Goble, O. L. *J. Sci. Instrum.*, **30**, p. 110 (1953).
(8) Walker, P. M. B. *J. Sci. Instrum.*, **30**, p. 162 (1953).
(9) Carpenter, R. B., and White, J. U. *Analyt. Chem.*, **25** p. 1473 (1953).
(10) Dyson, E. D., and Redfern, J. British patent No. 689 856 (1952).
(11) Payne, E. L., and Story, J. G. *Wireless Engr*, **12**, p. 58 (1935).
(12) Bastin, D. H. *Electronics*, **21** (11), p. 106 (1948).
(13) Ives, W. J. *Electronics*, **22** (8), p. 100 (1949).
(14) Chapman, S., and Boydan, L. *Electronics*, **26** (1), p. 13 (1953).

Errors of friction wheel integrators

By J. G. L. Michel, M.Sc., National Physical Laboratory, Teddington, Middlesex

[*Paper first received* 11 *October, and in final form* 4 *November*, 1954]

Sharp-edged friction wheels moving across hard surfaces with a combined rolling and sliding motion are used as units for integration in a number of instruments varying in complexity from planimeters to differential analysers. In these applications it is assumed that, providing the bearing friction of the wheel is sufficiently small, the rotation of the wheel is a true representation of that component of its motion across the surface which is tangential to the wheel. This paper shows that, for finite bearing friction (however small), this is not true when there is any non-tangential (sliding) motion of the wheel; an expression is adduced for the amount of error, with a numerical example of the magnitude of this error in a type of integrator used in differential analysers. It is pointed out that errors due to this cause may always be reduced to negligible proportions in the case of the differential analyser, at the expense of increasing the time of solution.

few years ago the author, when investigating the accuracy the Bush (Gonella gear) type of integrators used on several ferential analysers,(1, 2) realized that it was impossible to ieve perfect accuracy with such mechanisms. Private mmunications from several countries showed that the cidence of the type of error studied in this paper had been lized by several other users of differential analysers; ough the same effect introduces errors in instruments with much longer history such as the polar planimeter, no tailed examination and analysis of this error seems to have en published hitherto.

ANALYSIS OF MOTION OF A FRICTION WHEEL

Although the original purpose of this investigation was ncerned with the rotation of a friction wheel by a disk tating beneath it (see Fig. 4), the analysis is concerned only th the instantaneous motion of the components, and is st studied in terms of the linear movement of a plane rface with which a friction wheel is in contact, as sketched Fig. 1. This analysis is then readily applied to the apparatus own in Fig. 4.

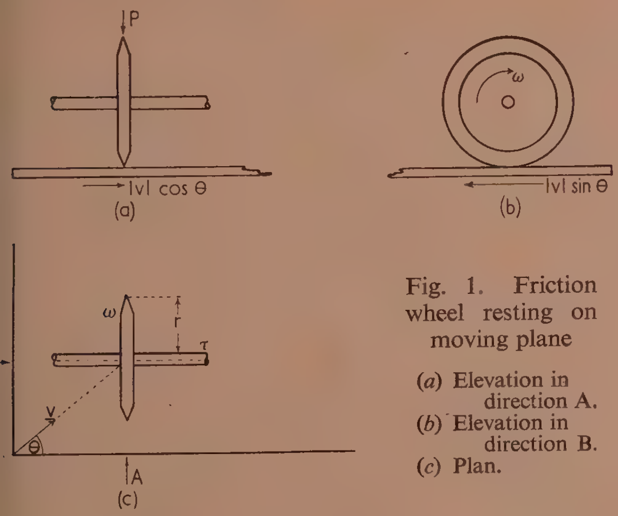


Fig. 1. Friction wheel resting on moving plane

(*a*) Elevation in direction A.
(*b*) Elevation in direction B.
(*c*) Plan.

The problem is concerned with the rotation of a wheel by e frictional forces between it and the plane upon which it sts, when that plane is moved under it linearly at a constant locity v in a direction making an angle θ with the axis of e friction wheel. In integrator applications, the perimeter the friction wheel should ideally rotate at a speed $|v| \sin\theta$ nd hence the wheel itself at an angular velocity $|v| \sin\theta/r$ rad/s). In the following analysis it is shown that it is impossible to attain this perfection except for the case $\theta = 90°$.

The actual motions of wheel and plane are indicated in the vector velocity diagram Fig. 2. The plane moves under the wheel at a speed v, and in a direction making an angle θ with the axis of the wheel. Ideally the periphery of the wheel would be driven at a speed $v \sin\theta = \overrightarrow{CA}$ (when slip $OC = v\cos\theta$ would occur in the direction of the axis of the wheel). However, the periphery of the wheel actually travels at speed $\omega r = BA$. The vector velocity of slip is $\overrightarrow{OB}$ making an angle α with $\overrightarrow{OC}$, and a loss of peripheral velocity $l = CB = v\cos\theta\tan\alpha$ occurs. We seek the ratio of the loss of rotations to those ideally expected

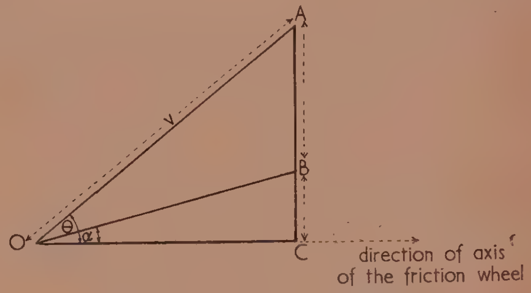


Fig. 2. Vector velocity diagram

$$L = CB/CA = \cot\theta\tan\alpha \tag{1}$$

The value of $\tan\alpha$ in equation (1) is obtained by considering the vector force diagram, Fig. 3. The frictional force due to slip between the friction wheel and plane, μP, acts along the direction of slip OB; the component of this force tangential to the wheel, CB, is τ/r, the force required to overcome the bearing torque τ of the friction wheel. Thus

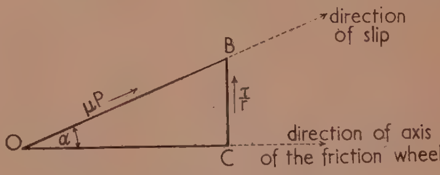


Fig. 3. Vector force diagram

$$|\tan\alpha| = \frac{\tau/r}{[\mu^2P^2 - (\tau^2/r^2)]^{\frac{1}{2}}} = (K^2 - 1)^{-\frac{1}{2}} \tag{2}$$

where $K = \mu Pr/\tau$, the ratio of the frictional force μP, to that force required to drive the friction wheel, τ/r. Inserting this expression in equation (1), we get the loss ratio

$$L = |\cot\theta|/(K^2 - 1)^{\frac{1}{2}} \tag{3}$$

where

$$K = \mu Pr/\tau \tag{4}$$

It is to be noted that the expression defining α, equation (2) is independent of θ, and that the analysis leading to equation (1) only holds for

$$\theta \geqslant \alpha \tag{5}$$

If $\theta < \alpha$, the tangential component of frictional force acting on the wheel is insufficient to exert the torque τ required to rotate the wheel, and under these conditions the wheel fails to turn at all.

APPLICATION OF THE RESULTS TO A DIFFERENTIAL ANALYSER

In differential analysers employing the Bush (Gonella gear) type of integrator, the plane surface of Fig. 1 is replaced by a rotating disk, and the friction wheel is displaced along a diameter of that disk (see Fig. 4). If the distance of the point of contact of the wheel from the centre of the disk is y cm, and it is being displaced at a rate $\dot{y}$ cm/s, whilst the disk is rotating with an angular velocity $2\pi\,\dot{x}$ rad/s, the instantaneous value of the angle θ is given by

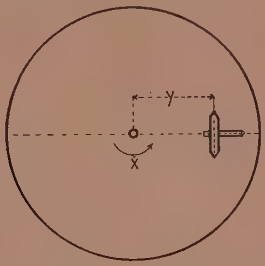


Fig. 4. Plan view of Bush type integrator

$$\cot\theta = \dot{y}/(2\pi y\dot{x}) \tag{6}$$

It is obvious that for a given displacement y, and a given speed of rotation of the disk $\dot{x}$, the loss ratio L of equation (3) is greater for greater velocity of translation $\dot{y}$. In designing differential analyser set-ups for solving differential equations, the designer has the opportunity of making this velocity $\dot{y}$ as small as he likes, at the expense of increasing the time of solution to his problem. It is important, therefore, that he should have some estimate of the errors due to the causes discussed in this note under the worst possible conditions. For this purpose, a preliminary estimate has been made of the physical parameters for a differential analyser being brought into operation at the National Physical Laboratory, and the errors due to these causes are calculated for the case where the wheel is translated right across the disk with the ratio $\dot{y}/\dot{x}$ constant—the maximum obtainable under normal conditions on this machine. From the differential analyser point of view this case is the set-up for producing rotations of the friction wheel proportional to the square of the rotations to the disk (see Crank(2) pp. 53–54).

For this integrator, the ratio K of equation (4) is approximately 72. The ratio $\dot{y}/\dot{x}$ occurring in equation (6) is 3 mm/rev. At values of y less than a certain value y_m, θ [given by equation (6)] is less than α [given by equation (2)], and no rotations are transmitted to the friction wheel when $|y| < y_m$. It follows from equations (2) and (6) that the critical value of y_m for which $\theta = \alpha$ is given by

$$y_m = \dot{y}/[2\pi\dot{x}(K^2 - 1)^{\frac{1}{2}}] \tag{7}$$

$$= 0{\cdot}0066 \text{ mm}$$

with the preceding numerical values of parameters.

If the displacement y is varied from 0 to 100 mm with the disk rotating in the above ratio, for a perfect integrator, the output of a friction wheel of 33⅓ mm radius should be $\int_0^y t\,dt/100 = y^2/200$ revolutions at a point where the displacement has reached a value of y mm (see Crank(2)). On the basis of the foregoing analysis, the actual output will be zero for $0 \leqslant y \leqslant 0{\cdot}0066$ mm. At any subsequent displacement y, the output will be at a rate of $(1 - L)$ times the theoretical output, where [from equations (3), (6) and (7)]

$$1 - L = 1 - \frac{\dot{y}}{2\pi y\dot{x}(K^2 - 1)^{\frac{1}{2}}} = 1 - \frac{y_m}{y}$$

Thus, whilst true total output when the friction wheel has reached a radius of 100 mm should be

$$\frac{1}{100}\int_0^{100} y\,dy = 50 \text{ revolutions}$$

the actual output will be

$$\frac{1}{100}\int_{y_m}^{100} y(1 - L)dy$$

$$= \frac{1}{200}(100^2 - 0{\cdot}0066^2) - \frac{0{\cdot}0066}{100}(100 - 0{\cdot}0066$$

$$= 49{\cdot}9934$$

The error is therefore just over one part in 10 000 and it is seen that the "dead zone" of 0·0066 mm at the centre of the disk has a negligible effect upon the accuracy, the significant part coming from the second term representing loss of rotations whilst motion is actually occurring.

Apart from mechanical design features aimed at increasing the value of the constant K, it is seen that in any given problem the accuracy can be improved by reducing the ratio $\dot{y}/\dot{x}$. Mathematically it is always possible to achieve this(2)—generally at the expense of increasing the time of solution. For the integrator to which these figures are related, design tolerances called for an overall accuracy of one part in 10 000. It is thus seen that, even under most onerous conditions, the slip of the friction wheel is unlikely to cause significant errors.

ACKNOWLEDGEMENTS

The work described above has been carried out as part of the research programme of the National Physical Laboratory and this paper is published by permission of the Director of the Laboratory. The author wishes to acknowledge the help of Mr. H. J. Norton in checking the arithmetical results and discussing the physical formulation of the problem.

REFERENCES

(1) HARTREE, D. R. *Calculating Instruments and Machine* (London: Cambridge University Press, 1950).
(2) CRANK, J. *Differential Analyser* (London: Longmans Green and Co., Ltd., 1947).

An instrument for the formation of visual images of ionizing radiations

By W. V. Mayneord, D.Sc., F.Inst.P., H. D. Evans, Ph.D., A.Inst.P.,* and S. P. Newbery, Institute of Cancer Research, Royal Cancer Hospital, London, S.W.3

[*Paper received* 25 *October*, 1954]

The apparatus described presents visual images of distributed radioactive sources. By means of image storage facilities, it is possible to build up the picture, line by line, over a long period of time and then to "read" the complete image at any convenient time thereafter. Problems of resolution and limits of detection are discussed and illustrated by photographs.

relation to a number of problems in pure and applied ysics it is a great advantage if visual images can be formed patterns of ionizing radiations. The range of interest is ry great, varying from the therapeutic and diagnostic use radioactive isotopes to problems in pure physics, such as -ray spectroscopy. Several different types of apparatus have ready been described, all presenting the final picture as a ries of spots on recording paper or film.(1,2,3)

In the apparatus described, the approach was somewhat ifferent in that visual presentation in a cathode-ray tube was esired. In earlier models of the apparatus(4,5) a persistent reen was used, but at low scanning speeds the persistence as still insufficient, so in the present system an image storage ibe was used.

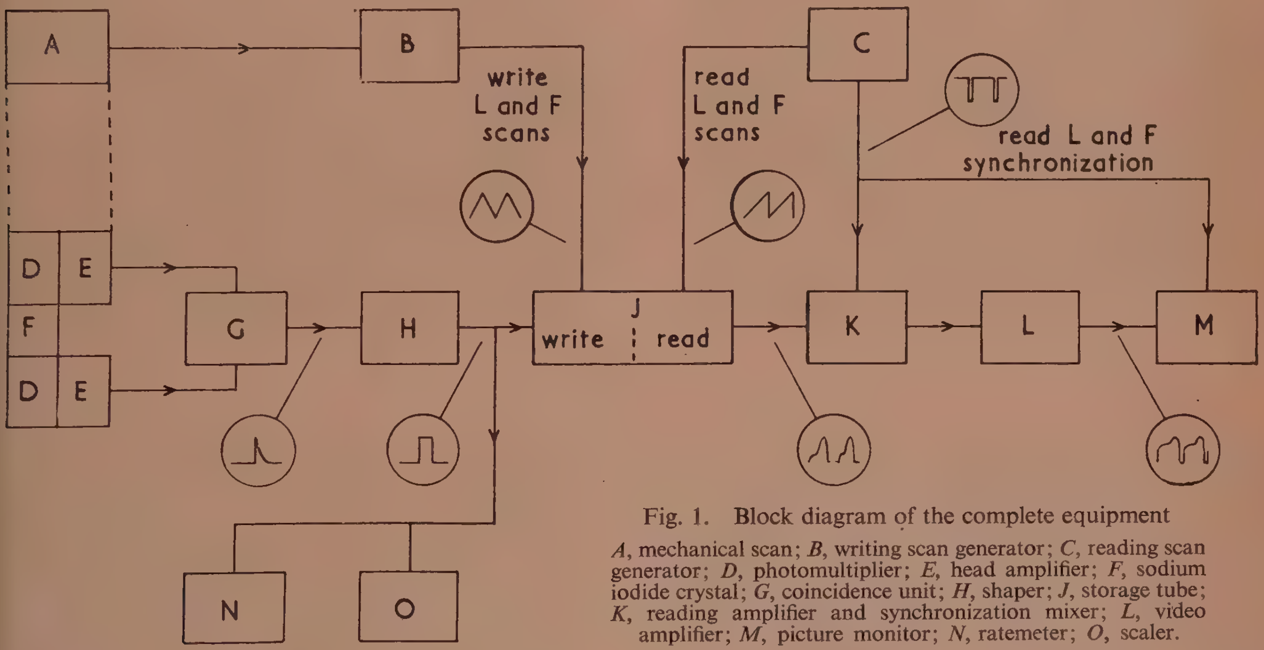


Fig. 1. Block diagram of the complete equipment

A, mechanical scan; *B*, writing scan generator; *C*, reading scan generator; *D*, photomultiplier; *E*, head amplifier; *F*, sodium iodide crystal; *G*, coincidence unit; *H*, shaper; *J*, storage tube; *K*, reading amplifier and synchronization mixer; *L*, video amplifier; *M*, picture monitor; *N*, ratemeter; *O*, scaler.

The authors were particularly interested in the fundamental hysical problems of image formation and interpretation hen approaching the statistical limits of significance or etection. In such problems the control of contrast, ability o deal with higher counting rates, ultimately higher resolution nd the possibilities of apparent reduction of background by rasure of parts of the picture at low counting rates, and the ossibilities of very high speed writing, make it worth while acing the extra complexity of the electronics in order to each the theoretical limits.

The apparatus consists essentially of two parts, a mechanical device for moving the detector accurately over the required field, and the electronic sections concerned with the detection of the radiation and the ultimate storage and presentation of the final image. A block diagram of the whole equipment is shown in Fig. 1.

MECHANICAL SCANNER

The earlier forms of the apparatus(4,5) used a radial scan but this was found to have some undesirable features, particularly the variation of size of field with distance of the emitting object. It was therefore decided in the present instrument to build a mechanical system which traversed the source in a series of parallel lines, with the axis of the radiation collimating system perpendicular to the area viewed. The maximum area which can be scanned is $18 \times 13\frac{1}{2}$ in. but provision is made by means of a simple pantostat for reducing it to $\frac{3}{4}$, $\frac{1}{2}$ or $\frac{1}{4}$ of this maximum size. The main frame (Fig. 2) is 5 ft 5 in. long and 2 ft 3 in. wide, carrying two $\frac{7}{8}$ in. diameter bars A forming runners for the frame movement, on which are carried two platforms B and C linked by frame D which is 29 in. long. Each platform carries a further pair of runners E and F at right angles to the first pair A, on each of which there is a carriage, one of which G supports the detecting system H and the other J provides the drive. The bar K, pivoted at a point L on the frame D, transmits the drive from the carriage *J* to the detector carriage *G*. By altering the position of the pivot point *L* along the bars *D* and *K*, the magnitude of the line-scan may be varied. The motor *M* drives a reversing Archimedian screw *N*, which traverses the carriage *J* back and forth along the runners *F*. A worm on the same shaft as the screw *N* drives a helical gear *O* keyed to a shaft *P*, which drives a second screw *R* of the same type as *N* through a Geneva movement *S*, so that the screw *R* is rotated a quarter turn each time the carriage *J* reaches either end of its traverse. A bar *T* pivoted to the main frame at *U* is traversed back and forth by the screw *R*, and the platform *C* picks up its movement from this bar at a point chosen to give the required magnitude of frame traverse. The gearing is such that the counter carriage *G* traverses a hundred parallel lines at uniform speed taking three seconds per line, the movement from one line to the next being carried out during the turn-round time at the end of each line, amounting to about $\frac{1}{40}$th of the total line time. A pneumatic damping system *V* practically eliminates the bounce at the end of each line. Two wire-wound potentiometers *W* and *X* are supplied with about 6 V d.c., and sliders fixed to the respective line and frame carriages pick up a voltage which is used to drive the writing scans of the storage tube in synchronism with the mechanical scans. All four carriages run on ball-bearing kinematic mountings. In normal use the apparatus is supported on four legs about 3 ft above the floor.

---

* Now at Department of Instrument Technology, Imperial ollege of Science and Technology, London, S.W.7.

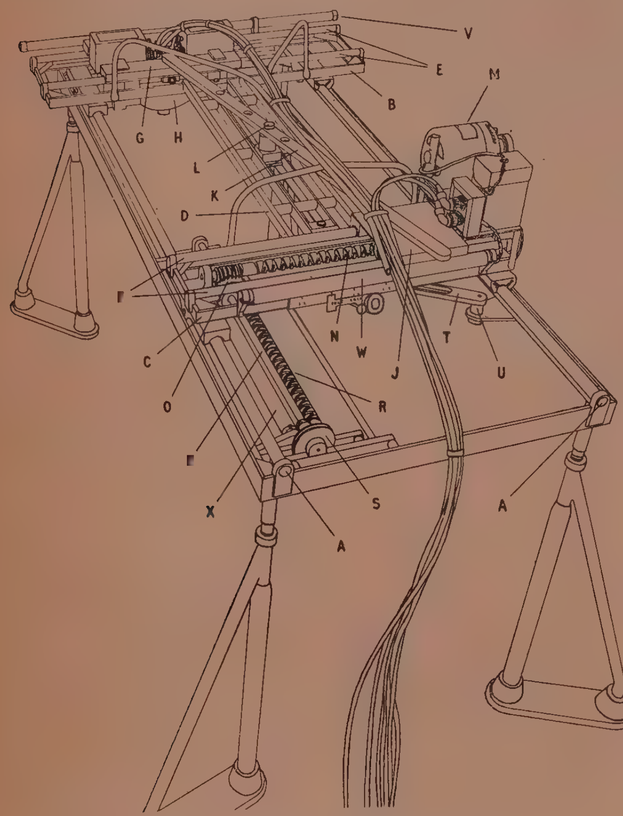


Fig. 2. The mechanical scanner

The time for the scanning of a complete frame is approximately six minutes. By the incorporation of limit switches the apparatus may be used for either continuous running or single-frame exposures.

THE DETECTOR SYSTEM

As the apparatus was primarily designed for the survey of radiation fields due to γ-ray emitting isotopes, the detector described is suitable for such purposes but obviously, by substitution of other detectors, the use may be extended over a very much wider range of radiations. In the first apparatus$^{(4)}$ a Geiger counter was used as detector but this was replaced by a scintillation counter.

In the detection of high energy γ-radiation the final background will be largely determined by scattered radiation from surrounding objects, and it is of the highest importance that the detector should be shielded in all directions except that from which the radiation is to be detected. This is, indeed, one of the major problems in the design of equipment of this type.

In the present apparatus the head unit, seen at *H* in Fig. 2, consists of a coincidence scintillation counter and its head amplifiers.

Two type 5659 photomultipliers (by Electric and Musical Industries Ltd.) are placed face to face, with a cylindrical perspex capsule containing a thallium activated sodium iodide crystal in paraffin, between them, the cathode ends of the multipliers touching the ends of the capsule. The collimator, consisting primarily of a cylinder of lead or tungsten alloy (density 16), 5·5 cm long and 3 cm in diameter, with an axial aperture, points vertically downwards. Additional lead shielding surrounds the crystal and photomultipliers, and provision is made for altering the aperture from 1 to 20 mm merely by replacing the cylinder by another having a different aperture.

The two head amplifiers are situated above the light-tight enclosure. Each consists of a three valve fed-back amplifier and cathode follower, having an overall gain of 50, 150 or 450 times (selected by a switch) in order to take up tolerances in photomultiplier performance. They derive their power, and feed their output back, through six-way cables connecting them to the coincidence unit. The circuit of the amplifier is very similar to that used in the type N509 scintillation counter (by Ekco Electronics Ltd.).

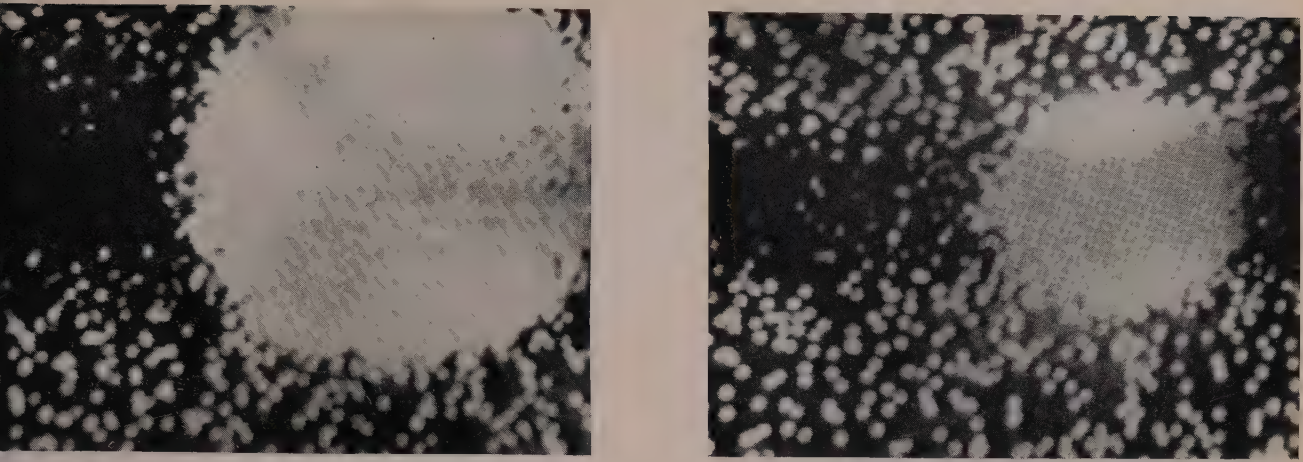
The head amplifiers feed their outputs to two discriminator circuits,$^{(6)}$ the output pulses from which are further sharpened to give a 0·5 μs wide pulse. After passing through buffer stages, these pulses are mixed in a diode coincidence circuit, the whole system having a coincidence resolving time of approximately 0·3 μs. Cathode follower outputs are provided for both single channels and the coincidence channel. A stabilized power pack for the discriminator and coincidence units follows standard design and incorporates two oscillator type e.h.t. supplies for the photomultipliers.

The coincidence output is used to modulate the writing side of the storage tube and may also be monitored on a standard scaler or ratemeter.

THE STORAGE TUBE

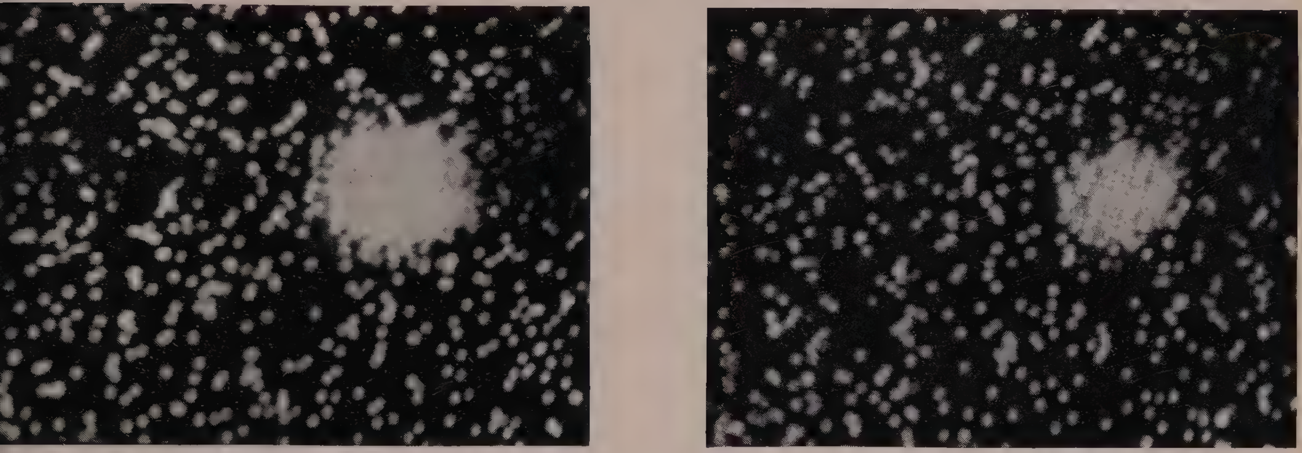
The following brief description of the storage tube is intended only to provide the reader with the information necessary to understand the working of the apparatus described. Further details of this type of tube may be found in the literature$^{(7, 8)}$ and the description is confined to the E.M.I. type VCRX 350, used in this apparatus.

Reduced to its bare essentials, the tube consists of an orthodox magnetically focused and deflected cathode-ray tube forming the writing section, placed face to face, in the same envelope, with a C.P.S. Emitron pick-up tube (by



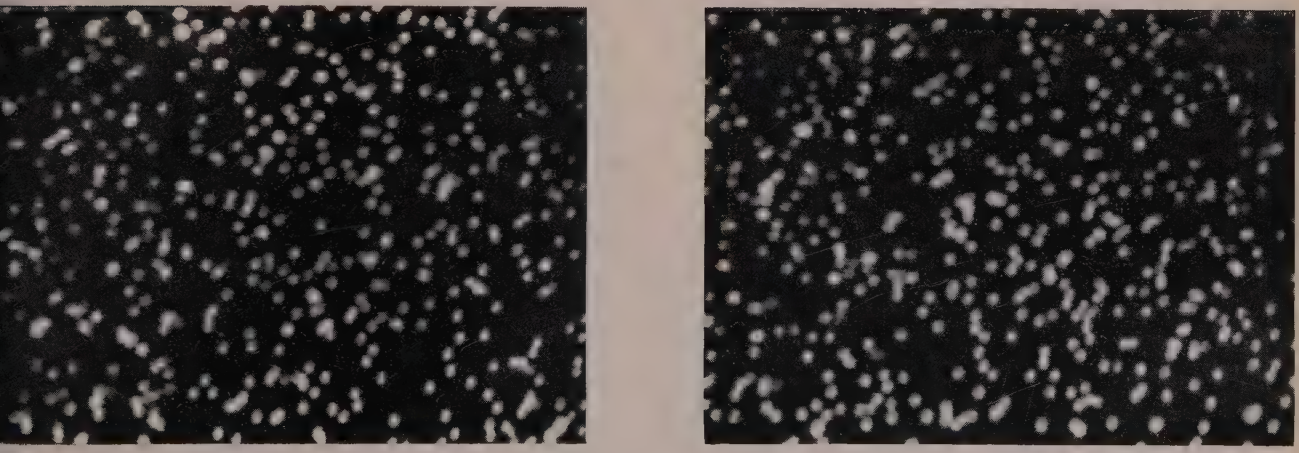
(*a*) 20 mm collimator; 14719 counts

(*b*) 10 mm collimator; 5549 counts



(*c*) 5 mm collimator; 2102 counts

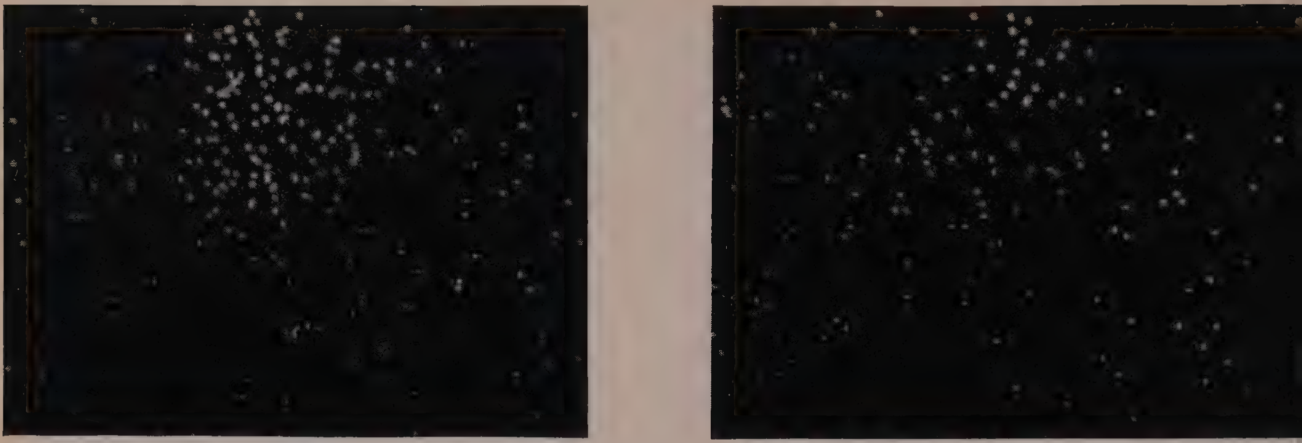
(*d*) 3 mm collimator; 1337 counts



(*e*) 1 mm collimator; 937 counts

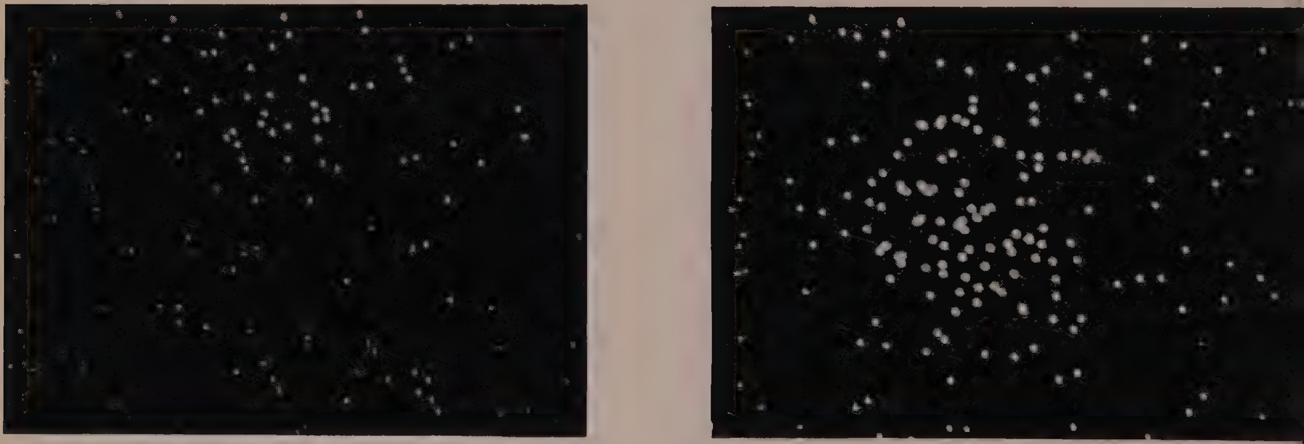
(*f*) solid block; 908 counts

Fig. 3. Point source, showing effect of collimator aperture



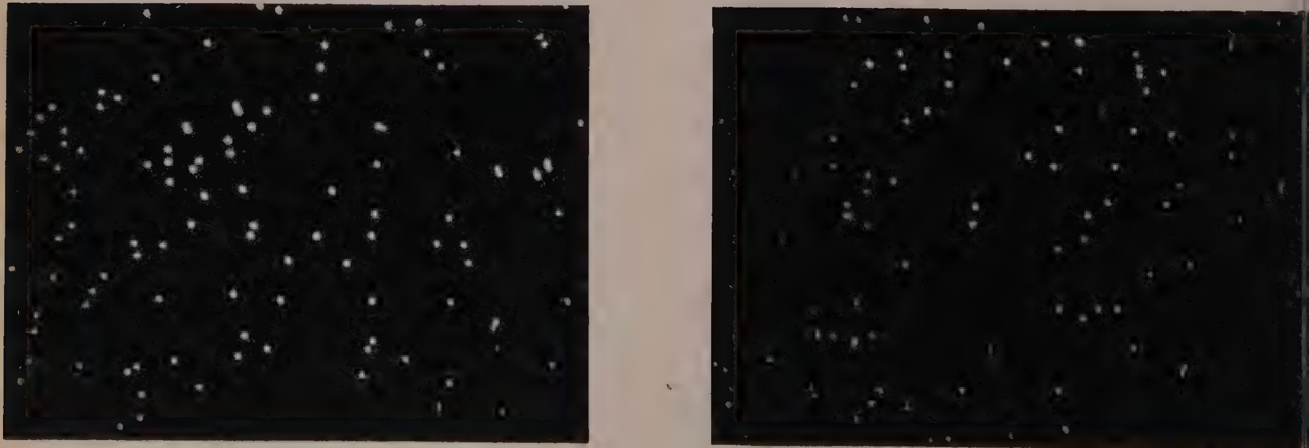
(*a*) 18·5 μc; 10 mm collimator; 264 counts

(*b*) 18·5 μc; 5 mm collimator; 152 counts



(*c*) 18·5 μc; 3 mm collimator; 138 counts

(*d*) 11·8 μc; 10 mm collimator; 189 counts



(*e*) 11·8 μc; 3 mm collimator; 118 counts

(*f*) random background; 120 counts

Fig. 4. Square source at low levels of activity

ectric and Musical Industries Ltd.) in which the photo- nsitive mosaic is replaced by a grid covered with a thin yer of insulator. The writing beam is modulated by the gnal to be stored, and forms a pattern of charge on the orage grid. This grid is then scanned, from the other side, y a low-velocity electron beam, which is modulated by the harge pattern as it scans over it, and is received by a collecting ectrode on the writing gun side of the storage grid. The gnal at the collector is of the same type and magnitude as at of a standard C.P.S. Emitron camera pick-up tube.

THE WRITING SECTION

Due to the low speed of the mechanical scan, the deflecting rcuits are virtually d.c. and line and frame scan circuits are entical. The slider of the potentiometer on the mechanical ystem is connected to one grid of a cathode-coupled double iode stage, the potential on the other grid being the picture hift control. The anode of the first section is directly oupled to the grid of a cathode follower having the deflecting oils as load. Feed-back from the cathode to the first triode rovides the amplitude control.

The writing beam is normally cut off, but the bias is lifted y the individual counting pulses received from the coincidence rcuit. In order to provide a fixed amount of charge on the orage grid for each count, a trigger circuit stage is inter- osed in which both pulse height and width are controllable.

HE READING SECTION AND PICTURE MONITOR

The reading scan is provided by a miniature 300 line, 0 frames/s sequential system following normal television ractice and the signal amplifier and synchronization mixing rcuits are of orthodox design. The picture is presented on 5 in. diameter television studio monitor tube, and is ynchronized directly from the timing pulses in the television ave-form generator. The video amplifier again follows ormal practice. A cathode follower output is also provided nd feeds a projection television system with about 1 V of icture and mixed synchronizing pulses. This presents a ll size picture (18 × 13½ in.) in addition to the image seen n the monitor situated in the main rack.

EXPERIMENTAL RESULTS

Both multipliers work at 1700 V, the amplifier gains are 50 times, and the discriminator bias settings are 5 V and V. The absolute efficiency of the coincidence counter with 5 mm collimator aperture, for the γ-radiation from ^{198}Au, xpressed in terms of counts/quantum entering the crystal, 37% when the background is 0·3 to 0·4 counts/s. A typical ngle channel efficiency, for the same background counting te, is 19%.

The coincidence method is probably worth while if the aximum sensitivity is required, but for normal work the mplification arising from the use of a single multiplier ounter outweighs this in most cases.

While the reading process does not remove charge from e storage mesh, there is a slow discharge taking place uring reading, since some of the electrons strike the mesh stead of passing through. This effect is most marked when e picture consists of a number of small discrete spots, but slow enough to allow several minutes reading of such a attern. When such pictures are expected, it is normal erefore to defocus the writing beam slightly, in order to crease the spot size and it is then possible to read for at ast fifteen minutes without serious deterioration of the cture. If the image consists of broad masses, where the writing spots overlap, then pictures can be retained for at least an hour with continuous reading taking place. Storage times, under conditions where the reading beam is cut off, extend over hours and probably days without any loss of picture quality, and it is normal practice to keep the beam off during writing so that the clearest pictures may be obtained.

Image resolution and limits of detection are two inter-connected problems. For a given resolution, as the number of quanta is reduced, there comes a stage when contrast and eventually shape are lost, though the presence of a broad mass is still evident. If now, some definition is sacrificed, it is possible to see shape once again. In addition, if the scale of the picture is reduced, the eye is often able to distinguish shape, where a larger picture appears quite indistinct. This question is well illustrated in the visual field by Rose,(9) but with the apparatus described even smaller numbers of quanta/picture can give recognizable outlines, largely because of the lower definition.

In this apparatus, resolution and sensitivity are both functions of the collimator aperture. Assuming a perfect collimator, the definition is a linear function, and the sensitivity a square function of the collimator diameter; clearly, if the aperture is increased, sensitivity increases more rapidly than definition deteriorates. In the practical case, the problem is complicated by penumbra effects and the distance of the source becomes important. The source should be as close as possible to the detector, and unless a high quantum flux is available, definition may have to be sacrificed for sensitivity.

The optimum type of collimator has been found to be of about 1 cm aperture, and at least 5 cm long, to reduce the acceptance angle. Under these conditions, scattered radiation does not cause deterioration of picture quality, since only those quanta scattered through an angle slightly either side of 180° are accepted. This fact has been clearly shown experimentally, where the addition of scattering medium above a source has not spread the image at all.

The results of a definition experiment are shown in Fig. 3. The source was a "seed" of radioactive gold of strength 600 μc, 2·5 mm long and 0·75 mm in diameter and for the purpose of this experiment could be regarded as a point source. This was placed at 25 cm from the crystal and scanned with five different sizes of collimator and with an identical solid block in place of the collimator, giving the true background, including the radiation passing through the lead shielding. The 20 mm collimator tapers from 20 mm at the open end, to 10 mm at the end nearest the crystal, over a distance of 5·5 cm. All other collimators are parallel holes of the diameter given, and length 5·5 cm. The blank patches in line with the source are due to a change in black level, caused by the intense white area.

These pictures are strictly the image of the collimator seen by the source, since the latter is small and far from the counter. Measurements of the diameters of the circles correspond accurately with the penumbra of the respective collimators.

A series of photographs showing the effects of collimator aperture, near the limit of detection, is shown in Fig. 4. The source is a perspex cell, 3 × 3 cm containing 5 ml. of ^{131}I solution. The total field size is 11·4 × 8·6 cm and the source was 25 cm from the crystal. A random background is given for comparison purposes.

It is interesting to note that in the absolute limit, the trained eye can recognize a non-random picture better than a statistical analysis of the distribution.

The problems associated with the loss of an image in the background are illustrated, in the lower limit, by the photographs already mentioned, but a larger programme is under way, investigating sizes, relative concentrations and depths of radioactive sources in large volume diffuse sources. The results of this work will be reported in a later paper.

The present paper has described only the radioactive detection application. A minor modification permits the apparatus to be used for making radiographs. A low-energy γ-emitter is fixed to the counter carriage so that the radiation passes at all times into the collimator. If, then, the object is placed between source and counter, and held stationary, the apparatus forms a true radiograph with a radiation dose to the object as low as 1 μr.(10, 11)

Clearly also the storage principle may be applied to a large number of different purposes with, in many cases, a very much higher sensitivity. For example, an X-ray spectrograph is under consideration where the sensitivity may be as much as 1000 times greater than conventional patterns, using direct photographic recording.

ACKNOWLEDGEMENTS

The authors wish to express their thanks to Mr. H. J. Hodt for the design and construction of the mechanical scanning unit. Invaluable co-operation and assistance in the use of their storage tube were given by Professor J. D. McGee and by Mr. S. Webley and Mr. J. A. Lodge of Electric and Musical Industries, Ltd. Thanks are due to the Department o Physical Research of the Admiralty for permission to use the storage tube, and to the Medical Research Council and the Nuffield Foundation, who financed the work.

REFERENCES

(1) Cassen, B., Curtis, L., Reed, C., and Libby, R *Nucleonics*, **9** (2), p. 46 (1951).
(2) Anger, H. O. *Amer. J. Roentgenol.*, **70**, p. 605 (1953).
(3) Brownell, G. L., and Sweet, W. H. *Nucleonics*, **11** (11), p. 40 (1953).
(4) Mayneord, W. V., Turner, R. C., Newbery, S. P. and Hodt, H. J. *Nature* [*London*], **168**, p. 762 (1951).
(5) Mayneord, W. V., and Newbery, S. P. *Brit. J. Radiol.*, **25**, p. 589 (1952).
(6) Cooke-Yarborough, E. H. *J. Sci. Instrum.*, **26**, p. 9 (1949).
(7) Knoll, M., and Kazan, B. *Storage Tubes* (New York John Wiley and Sons Inc., 1952).
(8) Pensak, L. *R.C.A. Review*, **15**, p. 145 (1954).
(9) Rose, A. *J. Opt. Soc. Amer.*, **43**, p. 715 (1953).
(10) Mayneord, W. V. *Brit. J. Radiol.*, **27**, p. 309 (1954).
(11) Evans, H. D. *Sci. J. Roy. Coll. Sci.*, **24**, p. 106 (1954).

An automatic pressure recorder for the study of gas phase kinetics

By D. Patterson, B.Sc., Ph.D.,* and R. C. Seymour, B.Sc., A.Inst.P., Department of Physical and Inorganic Chemistry, University of Bristol

[*Paper received* 11 *November*, 1954]

An automatic pressure recorder suitable for kinetic studies in gas phase reactions in a constant volume system, has been described. The instrument has been used up to pressures of 100 cm of mercury, and follows rise or decrease in pressure to 0·5 mm of mercury. A self-balancing servomechanism applies an external pressure equal to the pressure in the reaction system, and the magnitude of this pressure is continuously recorded on a pen-chart as a function of time.

In the study of reaction kinetics in gaseous systems, the reaction rate may often be conveniently determined by following the change in pressure of a fixed mass of the reactants in a system of constant volume. If at some temperatures the rate of change of pressure is slow, the procedure of taking individual readings of pressure over long periods can be tedious. An automatic recorder has been designed and constructed to provide continuous readings of pressure over a period of some hours.

The apparatus is capable of recording pressure changes in the range 100–5 cm of mercury, to an accuracy of about 0·5 mm.

Other types of automatic pressure recorder have been described, depending for their operation upon electronic(1) or optical(2) principles, or a combination of both,(3,4) but none of these appears suitable for the type of investigation referred to above, in which the system is to be kept at constant volume.

PRINCIPLE OF OPERATION

The principle of the method is to balance the changing internal pressure in the reaction system by raising or lowering a mercury reservoir. In this way the volume of the system i kept constant, and exact balancing of the internally- and externally-applied pressure is obtained, by keeping th meniscus of the mercury confining the reacting gases at fixed mark. This is done automatically, by the arrangemen shown in Fig. 1, in which an electrical servomechanism connected to the platinum contacts a and b (fused into th

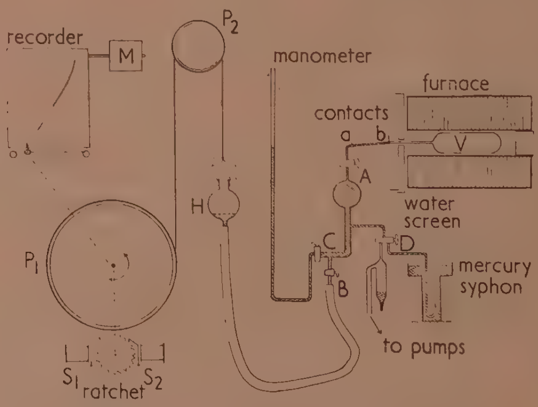


Fig. 1. Automatic pressure recorder

---

* Now at Imperial Chemical Industries, Ltd., Welwyn Garden City, Herts.

apillary tube) ensures that the mercury thread just touches ne contact *b*.

If the pressure in the reaction vessel *V* should rise, the neniscus tends to be displaced from *b* towards *a*, but when nis occurs, the mercury reservoir *H* is raised, and the amount y which it has to be raised in order to restore the balance s recorded. At constant pressure, the mercury thread is, vith respect to the contacts, in a state of make and break, o that when the pressure in the reaction system falls, there s continuous contact between the mercury thread and *b*. The reservoir is then lowered until balance is obtained as efore.

METHOD OF OPERATION

The reaction vessel is first outgassed under vacuum, and he temperature of the furnace adjusted to the value at which he reaction is to be carried out. Exact control of the temerature of the furnace is essential as it has been found that t 400° C, a fluctuation of $\pm 0{\cdot}5°$ C occurring while the eating elements are being switched can cause pressure hanges, due to thermal expansion of the reacting gases, vhich completely mask the changes due to the chemical eaction.

A measured volume of the gas under investigation is ntroduced through the syphon to an evacuated bulb immeliately below the tap *A*, which is kept closed. The recorder notor and control circuit are then switched on, and taps *3* and *C* opened. To allow the reaction to commence, tap *A* s now opened, and the gas is allowed to enter the evacuated eaction vessel. The height of the mercury reservoir *H* is djusted by hand until the mercury thread just touches the ontact *b*. Tap *C* is then closed, and a mark made on the ecorder chart to indicate the pressure at zero time. (The eason for closing *C* immediately after the start of an experinent is that the operation of the control system depends on aving a constant volume of mercury in the apparatus etween the reservoir and *b*. If *C* were open, mercury would low in or out of the manometer, and this condition would ot be fulfilled.)

From now on, the position of *H* is controlled automatically y taking up or paying out from pulley P_1 an inextensible vire which passes also over fixed pulley P_2. The first pulley s driven by a pair of solenoid-operated ratchets, one of vhich (S_1) is arranged to lower the reservoir and the other S_2) to raise it. The position of the pulley, and thus the eight of the reservoir, is recorded as a continuous trace as a unction of time on the recorder chart, the pen of which is irectly geared to the pulley spindle.

The method of operation of the electrical control can be een from Fig. 2, in which the contacts *a* and *b* are those eferred to in discussion of Fig. 1. Electrical contact between hem is made or broken by movement of the mercury hread.

If the pressure in the reaction system is sufficiently greater han the externally applied pressure, so that *a* and *b* are not o connected, the current flowing through the control solenoid $_3$ is small. The movable contact *c* will touch *e*, and cause olenoid S_2 to operate, thus raising the mercury reservoir y one notch of the ratchet each time the interruptor sends a .c. pulse into the circuit containing the two solenoids, $_1$ and S_2. When the reservoir has been raised to a height uch that the mercury thread again connects *a* and *b*, the node current increases sufficiently to bring the movable ontact *c* on the control solenoid S_3 into contact with *d*. As ong as this occurs, the pulses from the interruptor cause solenoid S_1 to lower the reservoir, until, as a result, the mercury thread no longer connects *a* and *b*. The system is a simple type of self-balancing servomechanism.

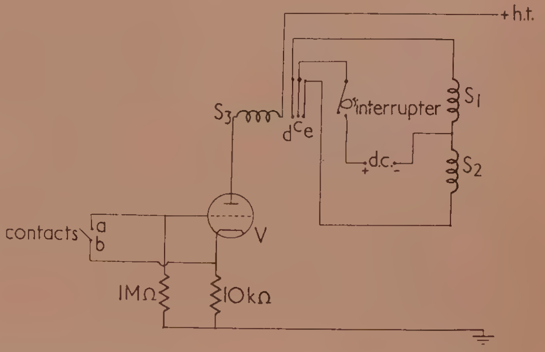


Fig. 2. Automatic recorder circuit

The interruptor consists of an eccentric cam driven by the recorder motor *M* and gives about three pulses per second. Each pulse causes the reservoir to be raised or lowered by 0·25 mm. If the pressure in the reaction system remains constant, the solenoids operate alternately as described above, but if the pressure falls, solenoid S_1 operates more frequently than solenoid S_2, and conversely, if the pressure rises.

CALIBRATION

It is necessary to calibrate the device before the results can be interpreted in terms of centimetres of mercury.

It is necessary to determine the height of mercury in the open manometer when the pressure in the reaction vessel is atmospheric. This is conveniently done by removing the reaction vessel completely, and setting the control circuits going, with tap *C* open. The height of mercury in the manometer is then read from a cathetometer. The difference between this height and the height of mercury in the manometer at the beginning of an experiment, has to be added to the barometric pressure in order to obtain the initial pressure in the reaction system.

The movement of the recorder pen corresponding to a known pressure change in the reaction vessel has now to be determined. This is done by observing changes in the height of mercury in the manometer, when the taps *B* and *C* are open (so that the levels in the manometer and reservoir are the same), and measuring the corresponding length of the line drawn by the recorder pen, without the paper drive running.

ACKNOWLEDGEMENT

Thanks are due to Mr. R. Ricketts for designing and making the electrical circuit.

REFERENCES

(1) Price and Zemany. *Rev. Sci. Instrum.*, **21**, p. 261 (1950).

(2) Zeigler. *Ann. Phys.* [*Leipzig*], **551**, p. 175 (1943).

(3) Tadayon. *Rev. Sci. Instrum.*, **22**, p. 534 (1951).

(4) Thomas and Lichtin. *Rev. Sci. Instrum.*, **24**, p. 661 (1953).

Piezoelectrically-activated low-frequency mechanical resonators

By J. F. W. Bell, Ph.D., A.Inst.P., The Royal Naval College, Greenwich, London

[*Paper received* 28 *July*, 1954]

Mechanical resonators using two piezoelectric crystals have been studied as four terminal networks. The constants of the equivalent electrical circuit have been determined for a number of flexural modes of various circular plates supported at the centre, i.e. the Chladni's plate type of resonator.

A 1000 c/s oscillator with frequency stability of a few parts in 10^4 using a 2 in. diameter plate is described.

For many years it has been the practice to use electromechanical resonators in place of tuned circuits. At audio frequencies the tuning fork and the reed, which are widely employed as the control elements in fixed-frequency oscillators and filters, are good examples.

This paper describes some low-frequency flexural resonators which are excited by very active piezoelectric crystals such as Rochelle salt, ammonium dihydrogen phosphate (A.D.P.) and lithium sulphate. The crystals are small compared to the rest of the system and contribute little stiffness and mass. Because of the low electromechanical coupling two crystals are used, one for the applied voltage and the other for the output voltage. At resonance the two voltages are of the same order of magnitude.

While keeping the investigation fairly general it was held in mind that, for a practical circuit element, the resonator should be of convenient shape, small size and with as high a Q-factor as possible. Other desirable features, which are also common to radio-frequency quartz resonators, such as freedom from adjacent resonances and a low temperature coefficient, have also been sought.

PRELIMINARY INVESTIGATION

Measurements were carried out on a circular Chladni's plate, 14 in. in diameter and ⅛ in. thick supported at the centre. A comprehensive account of the mode patterns and frequencies of such a plate is given by Waller.(1) Two large crystals of A.D.P. were cemented along a diameter at opposite sides of the centre.

A signal from a variable frequency oscillator was applied to one of the crystals. The voltage appearing across the other crystal was applied, *via* a cathode follower, to an oscilloscope or valve voltmeter as required. A survey of the frequency spectrum showed a large number of resonances. The mode patterns of these resonances were easily identified; those with nodal diameters predominated. They were symmetrically disposed relative to the exciting crystal which would therefore be in an anti-nodal region. The orientation of the pattern cannot be changed by holding the plate at any particular point, the effect is merely to damp the resonance very strongly. Resonance cannot be restored by frequency adjustment. It would therefore appear that the position of the crystal completely governs the orientation of the modes it excites. Table 1 summarizes the observations on this plate. The mode pattern is indicated by the number of nodal diameters (3D refers to the mode with three nodal diameters).

It will be noted that the output impedance was several megohms. Later work showed that the phase difference between the input and output voltages deviated from ±90 when the load had a resistive component.

BARS AND REEDS IN FLEXURE

These have been studied extensively by various investigators. The resonant frequencies are given by the expression

$$f_0 l^2/t = \kappa v \qquad (1$$

f_0 is the resonant frequency, l the length, t the thickness, v the velocity of compressional waves in the material of the resonator and κ a numerical constant. For bars κ has the values 1·02, 2·84, 5·53, etc. For reeds κ has the values 0·0617, 0·386, 1·08, etc. It will be seen that the fundamental frequency of a reed is very much lower than that of a bar of the same length. To vibrate satisfactorily, however, reeds must be clamped in a massive clamp. Similarly, bars must be supported precisely at nodes which are difficult to locate as the presence of the crystals will move them from the theoretical positions. Such considerations, while not necessarily excluding the use of these vibrators, render their adaptation more difficult than that of plates which are simply supported at the centre.

Measurements were carried out to the extent of establishing that electrical performances comparable with that of plates can be achieved. In the case of a reed with a fundamental frequency at 100 c/s it was found possible to avoid the excitation of the 630 c/s resonance by positioning the crystals near the clamped end, a point of inflection in this mode. Thus the reed had no resonance between the fundamental frequency at 100 c/s and the 1750 c/s resonance, a very desirable feature in filter circuits.

EQUIVALENT CIRCUIT

The equivalent circuit of a two-crystal composite resonator is shown in Fig. 1. It is the same as that given by Mason(2 for a single-crystal resonator with two separate pairs of electrodes. C_A and C_B are the electrostatic capacities of the crystals. The mechanical resonant system is represented by an equivalent mass m, a compliance c and a dissipation k. The two transformers represent the reversible transfer of

Fig. 1. The equivalent circuit of a two-crystal resonator

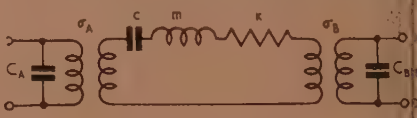


Table 1. *Some resonances of a* 14 × ⅛ *in. circular brass plate with A.D.P. crystals*

Frequency (*c/s*)	140	310	570	810	1200	1400	2180	2360
Mode pattern	2D	3D	4D	5D	6D			
V in/V out	2·8	1·1	9·4	1·1	4·7	2·7	3·5	1·0
R output (MΩ)	10½	10½	9½	8½	6½	6	6	5½
Phase of V out with respect to V in	150°	−30°	−30	−30	150	−30	150	−30

lectrical energy to mechanical energy by the piezoelectric ffect of the materials of the crystals. σ is the ratio of the isplacement velocity of the mass to the corresponding urrent i in the primary of the transformer. A small value of represents large electromechanical coupling. This circuit

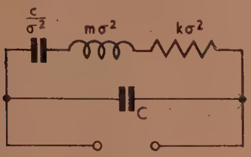


Fig. 2. The equivalent circuit of a single-crystal resonator

resents to the terminals of one of the crystals the familiar ircuit shown in Fig. 2 which is the equivalent circuit of a iezoelectric crystal near one of its resonances.

TRANSFER CHARACTERISTICS

Analysis of the equivalent circuit shows that the ratio r of he voltage fed into the crystal A to that appearing across rystal B is, at resonance, given by the expression

$$r = \pm jKC_B \qquad (2)$$

Feeding the signal the other way gives

$$r' = \pm jKC_A \qquad (3)$$

here $K = \sigma_A \sigma_B k 2\pi f_0$

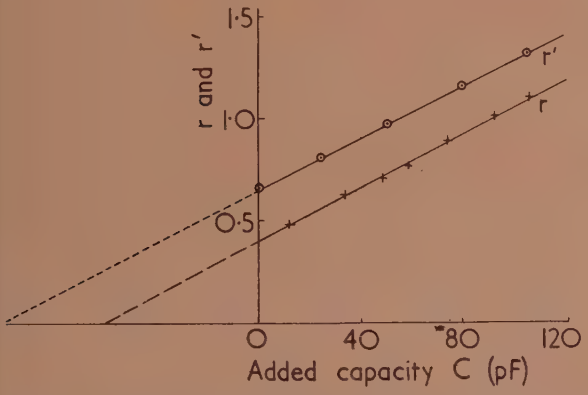


Fig. 3. Input to output voltage ratio (r and r') as a function of output capacity for plate 3, 2D resonance

f_0 is the resonant frequency of the mode, i.e. that frequency at which r is a minimum. The output voltage leads or lags the input voltage by ±90°, depending on the polarity of the crystals and the mode of vibration of the plate.

Measurements were carried out by adding capacity in parallel with that of the output crystal which, as above, was connected to a cathode follower. The input impedance was 25 MΩ and the input capacity plus that of the leads to the crystal was 17 pF. Typical graphs of r and r' plotted against C, the added capacity, are shown in Fig. 3.

In some cases it was found that the two graphs were not parallel. This was traced to the change in temperature of the crystals between the two sets of readings. The electrical properties of the Rochelle salt crystals which were used change very rapidly with temperature at room temperatures. In a particular case (plate 2, 3D resonance) the value of $1/K$ changed from 36 to 15 pF between 23 and 33° C.

OTHER MEASUREMENTS

To determine all the constants of a plate it is necessary to measure the Q-factor, the equivalent mass, the resonant frequency and the resistance across one of the crystals at resonance. Thus $4\pi^2 f_0^2 cm = 1$; $k = 2\pi f_0 m/Q$; $\sigma = (R/k)^{\frac{1}{2}}$ and $\sigma_A/\sigma_B = 2\pi f_0 R_A/K$. The Q-factor was determined by observing either the frequency response or the logarithmic decrement.

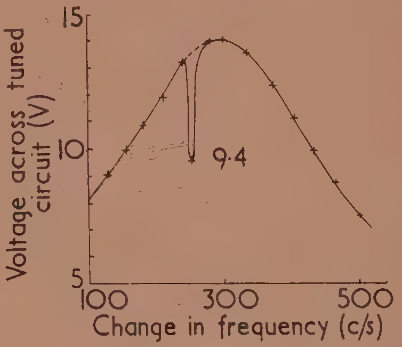


Fig. 4. The crevasse caused by the 3D resonance of plate 3 when crystal A was in parallel with a tuned circuit

The equivalent mass was found by measuring the drop in frequency δf when small masses δm were secured at antinodes

Table 2. *The constants of a selection of modes of some circular plates supported at the centre*

Plate	*Material*	*Thickness* *(mm)*	*Diameter* *(mm)*	C_A (pF)	C_B (pF)	*Mode*	f_0 *(c/s)*	r_{min}	r'_{min}	$1/K$ *(pF)*	Q	R_A *(MΩ)*	σ_A/σ_B	σ_A *(m/C × 10⁻³)*
1	mild steel (from rod)	1·14 ± 0·02	58·9	47	42	2D	1630	1·30	1·60	34	800	0·67	0·23	3·9
						3D	3965	1·15	1·30	39	950	0·39	0·38	2·5
2	brass (from sheet)	0·91 ± 0·02	50·5	64	34	2D(LF)	950	8·5	4·5	5	650			
						2D(HF)	1025	8·5	4·5	5	650			
						3D	2520	2·3	1·0	19	1100			
3	brass (from sheet)	4·16 ± 0·02	128·2	66	46	2D	790	0·65	1·20	81	4000	0·34	0·14	2·1
						3D	1960	0·40	0·65	148	4100	0·19	0·34	1·3
						4D	3580	0·42	0·60	132	4800	0·28	0·85	1·1

on the periphery of the plates. With small loading there was no reorientation of the nodal pattern. The expression $m = \frac{1}{2} f_0(\delta m/\delta f)$ gives the equivalent mass of the plate. Expressed in terms of the mass of the plate the equivalent masses for the 2D, 3D and 4D modes were $13\frac{1}{2}$, 9 and $11\frac{1}{2}\%$ respectively. In the case of most single-crystal resonators, e.g. the longitudinal bar, the equivalent mass is half the actual mass of the crystal, whatever the mode. For a circular plate the precise evaluation of the equivalent mass would involve a very difficult integration. If, however, the form of vibration is taken as $\xi = \xi_0(r/r_0)^3 \sin n\theta \sin \omega t$ where n is the number of nodal diameters, the equivalent mass becomes one-eighth of the total mass for all modes of this type. It would probably be of value to investigate other expressions of this form as it could also be used for the approximate evaluation of the resonant frequencies.

The resistance at resonance was measured by the Cady crevasse method for crystals.$^{(3)}$ A typical crevasse curve is shown in Fig. 4. The results on three plates are summarized in Table 2.

DISCUSSION OF RESULTS

For the plates of Table 2 the crystals were cemented tangentially at opposite ends of a diameter. The dimensions were $2 \times \frac{1}{2} \times t$ cm where t the thickness was always kept rather less than the thickness of the plate.

Plate 2 was found to have two 2D resonances. In one (the lower frequency), the crystals were at nodes and in the other they were at antinodes. This example of mode splitting is discussed below. In this case the equivalent circuit of Fig. 1 will not be applicable and analysis in terms of this circuit has not been followed up.

The values of r and r' show that in some cases the output voltage is greater than the input voltage, rather in the manner of a quarter-wave transformer. The low values of $1/K$ show at once the necessity for connecting the output crystal directly to a cathode follower.

As would be expected, the more massive the plate the better the Q-factor and general performance. It is expected that an improvement in Q will be obtained by vacuum mounting and when fused quartz plates (which also have a very low-frequency temperature coefficient) are used.

The value of σ_A/σ_B was checked for the 3D resonance of plate 3 by observing the crevasse for crystal B as well as crystal A. The value of R_B obtained was 0·65 MΩ. This gives a value for $\sigma_A/\sigma_B[=(R_A/R_B)^{\frac{1}{2}}]$ of 0·54 as compared to 0·34 by the other method. The difference is undoubtedly due to the difficulty of measuring R_B accurately because of the smallness of the crevasse.

MODE SPLITTING

In certain cases it was found that a mode would occur in two forms, one in which the crystals were at antinodes—this is the usual form of vibration—and a second in which the crystals were at nodes. The loading of the plates at an antinode would cause a drop in frequency of that form but not of the other as the load will then be at a node. The frequency of the two forms could be made to coincide by suitable loading. If one form is asymmetrically loaded the resonance can be made very weak indeed without altering the other significantly. The effects just described have their exact counterpart in the performance of electromagnetic cavity resonators which in turn are no more than the coupling of two resonant systems. This leads one to the most general form of the equivalent circuit of a plate for a number of crystals. It is similar to Fig. 1 with one transformer for each crystal and with one *cmk* circuit for each resonance coupled to each transformer.

APPLICATION TO OSCILLATOR CIRCUITS

The high Q of the plates makes them suitable for the control elements of stable low-frequency sinusoidal oscillators. A circuit which has been found to be suitable is shown in Fig. 5. The tuned circuit is necessary to select the mode in which the plate is to oscillate. The various circuit components are adjusted until the phase change round the circuit is 2π at the resonant frequency of the plate. The 0·02 µF blocking condenser was found to be necessary as, in the case of very thin crystals, it was found that 200 V d.c. sometimes caused the crystal to disintegrate over a period of hours.

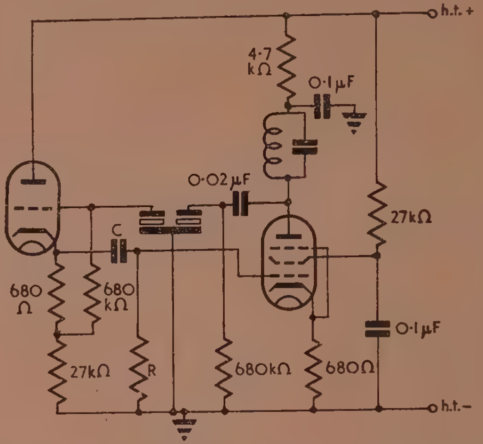


Fig. 5. A 1 kc/s oscillator using a plate as control element. The *CR* product and the tuned circuit were adjusted until the phase change round the circuit was 2π at the resonant frequency of the plate

An oscillator using plate 3 was constructed. A three-position switch enabled any of the first three modes to be selected. Other oscillators at about 1 kc/s using plates similar to plate 2 were used to investigate frequency stability. Apart from temperature drift the frequency remained constant to one or two parts in 10^4. The temperature frequency drift was 0·019% per °C. This is the approximate value expected for a brass plate. Work is being continued on fused quartz and other materials of low temperature coefficients.

ACKNOWLEDGEMENTS

The author wishes to make acknowledgement to Professor G. F. Nicholson and the Research Committee of the College for the generous facilities provided, and to thank him and other colleagues for their helpful discussions. The plates were made by Mr. S. G. Smith in the departmental workshop.

REFERENCES

(1) Waller, M. *Proc. Phys. Soc.* [*London*], **50**, p. 70 (1938); *J. Sci. Instrum.*, **31**, p. 410 (1954).
(2) Mason, W. P. *Electromechanical Transducers and Wave Filters* (New York: D. Van Nostrand Co. Inc., 1942).
(3) Cady, W. G. *Proc. Inst. Radio Engrs*, **10**, p. 83 (1922).

A servo-controlled microdensitometer for X-ray diffraction photographs

By J. R. Brown, B.A., H. K. Moneypenny, B.Sc., A.R.C.S., and R. J. Wakelin, Ph.D., A.Inst.P., A.I.M.

[*Paper first received* 26 *April, and in final form* 27 *October*, 1954]

The instrument is designed primarily for measuring densities and positions of lines on Debye–Scherrer photographs. The split beam principle is used, light passing through the film being compared with that transmitted by a linear density wedge. The measuring system consists of two photocells in a bridge circuit, controlling a servomechanism which automatically moves the wedge to the balance position. The density is indicated directly by a revolution counter. The accuracy is 0·004 units up to density 3.

s X-ray techniques improve it is becoming more and more nportant to have an instrument to measure accurately both ne intensity and the position of diffraction lines. Further, is often of interest to know the shape of such lines. This nay, in some cases, be carried out by using Geiger counter echniques. However, it is frequently advantageous to employ photographic film to record the whole diffraction pattern, nd then to use a microdensitometer to measure the optical ensity of the various small regions of the photographic nage. Optical density is defined in terms of the intensity I_0 ncident on the film and the intensity I transmitted through it y the relation

$$D = \log_{10}(I_0/I) \qquad (1)$$

he importance of the density D in X-ray work is due to its roportionality to the total number of X-ray quanta falling n unit area of the film in the region examined, provided hat D is less than a certain value which varies with the film nd the method of processing.

There are two types of instrument which may be used for neasuring density; in the first the film is interposed between ne light source and a photocell. By measuring the current hrough the cell with and without the film present, and nowing that this current is proportional to the light ntensity on the cell, the ratio I_0/I may be found. The success f the measurement depends on the constancy of the light ource both in position and intensity. In practice, the sagging f the filament and the fluctuations of voltage across it are ne factors which limit the accuracy of this type of measurement.

In the second type of densitometer, due to Dobson,⁽¹⁾ the ght beam is divided, part of it passing through the film and ne rest through a linear density wedge; after transmission the eams are compared and equalized by adjusting the position f the wedge. Fluctuations in the light source are unimportant since they affect both beams equally.

The instrument described by Taylor⁽²⁾ is typical of the Dobson type. In this instrument each light beam is selected in urn by a hand-controlled shutter, and the wedge is moved until qual galvanometer deflexions are obtained. The instrument simple and accurate, but tedious in operation. An automatic balancing system would increase the speed of operation nd reduce the fatigue incurred.

There are two main problems associated with the design f an automatic balancing system. In the first instance, nce a range of densities from 0–3 is often required, a light ux range of 1–1000 is involved. Therefore a very stringent ondition is imposed on the measuring system, which must e able to handle a signal varying by a factor of 1000. The econd difficulty arises from the fact that a single cell has to ifferentiate between light from the two paths and direct the edge in the appropriate manner.

Both these troubles may be eliminated by using two photocells in a bridge circuit. The difficulty of the wide signal range is overcome by the convenient experimental fact that a given change in density anywhere over the whole range causes the voltage on the bridge to change by a nearly constant amount. This occurs because the dynamic impedance of the photocells is inversely proportional to the light intensity over this wide range. The second difficulty does not arise. The resultant signal is positive or negative, depending on which of the light beams is the stronger.

No loss of accuracy arises from the use of two photocells instead of one because of the accurate linearity of vacuum photocells over the range of light intensities employed. This question is dealt with in detail later.

An ideal microdensitometer would be capable of measuring spots as well as lines on a film. For this purpose the dimensions of the light spot on the film should be variable between wide limits. Ideally, the area of film over which a single measurement of density is to be made should be capable of adjustment up to limits of 4 × 2 mm. The illumination should be substantially constant over the whole area measured, and the maximum attainable illumination should be sufficiently high to give an adequate response from the measuring system when the area is only 0·02 mm². To fulfil these requirements a very complex optical system would be needed. The system may be simplified, however, if the densitometer is designed for a specific purpose. The instrument described in this paper has been designed for measuring Debye–Scherrer films. Simplicity and high light intensities are achieved by using the reduced image of a lamp filament as the light spot.

As the instrument was required for research purposes and not for routine measurements, automatic recording was not considered necessary. The non-recording instrument described was considered to be more flexible than an automatic one. Conversion to automatic operation could be made with minor alterations as described later.

DETAILS OF DESIGN

(*a*) *Optical design.* The optical system is shown schematically in Fig. 1. Light from a projection lamp S, with a horizontal filament in the form of a tightly-wound helix, passes through the condensing lens, L_1, and the collimating lens, L_2, on to a semi-aluminized mirror, M. Part of the light passes vertically downwards from this mirror through a 1 in. microscope objective which forms an image of the filament on the optical density wedge. The second beam is reflected from the light-splitting mirror and passes through a similar microscope objective, forming an image of the filament on the film. After passing through the film and wedge the light is collected by further objectives fixed rigidly above the photocells, on to which diffuse patches of light are thrown.

The physical arrangement of the optical system is shown in Fig. 2. The light source is contained in an adjustable lamp housing. Before reaching the first lens, the light passes through slits which help to reduce the flare to negligible proportions, then through an iris diaphragm and a plane glass disk, the latter merely excluding dust. The size of the image on the film depends on the filament size of the lamp used. Two image sizes have been found convenient: 2 × 0·2 mm and 2 × 0·4 mm.

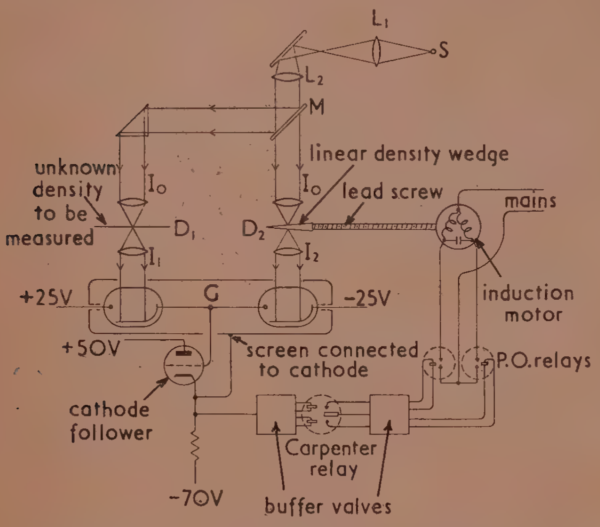


Fig. 1. Basic schematic diagram of microdensitometer system

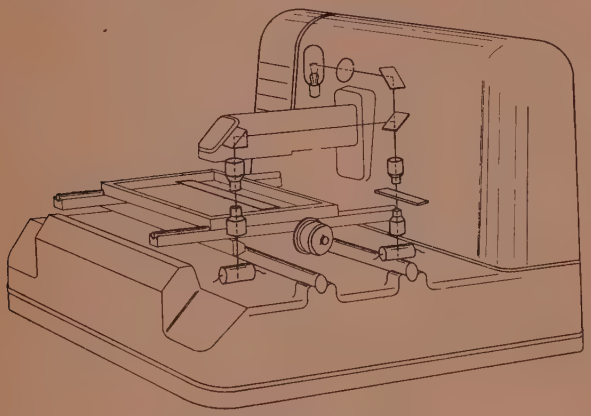


Fig. 2. Arrangement of the optical system in the complete instrument

The objectives are both capable of adjustment through ±⅛ in. for focusing. The optical density wedge is a graphitic one made by Ilford Ltd., 10 cm long with a density range 0–4 and, as near as can be judged by comparison with a second wedge, is linear over the whole range. The lenses of the optical system are mounted in dust-proof tubes, the interiors of which are finished in matt black.

(*b*) *Mechanical design.* A general view of the instrument is shown in Fig. 3. The base is made of black Tufnol and carries the photocells with their objectives and all the electronic equipment, including the power pack. It is completely enclosed by the main casting which carries the film carriage and wedge traverse, together with the motor and revolution counter which are illustrated in Fig. 4. The top casting containing the optics and lamp, fits over the motor and counter, as may be seen in the assembled instrument. The well-ventilated lamp housing is separate from the main body of the instrument to avoid excessive temperature rises.

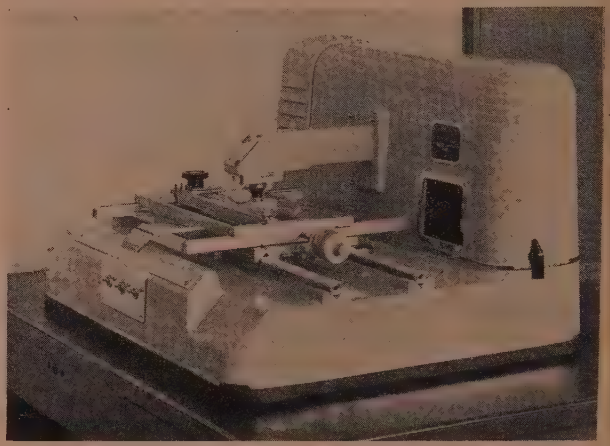


Fig. 3. Photograph of microdensitometer

The density wedge is moved by an accurately-ground lead screw with 100 turns of 1 mm pitch, mounted on bearings free from backlash. The position of the wedge is denoted by a zero-setting revolution counter, which counts units of one-tenth of a turn of the screw, i.e. a density of 0·004. The lead screw is driven by a Drayton induction motor running at approximately 120 rev/min. Micro-switches at the ends of the traverse safeguard against overshooting.

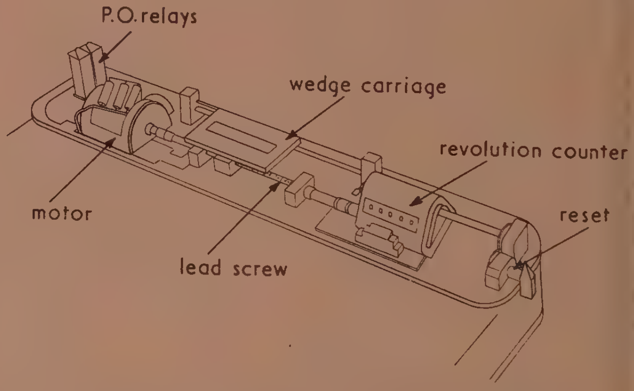


Fig. 4. Driving system for the optical wedge

Two interchangeable film carriages are available; one is for measuring intensities round the diffraction rings on orientation photographs. It consists simply of a turntable graduated in degrees and is equipped with a vernier reading to 0·1°. The second carriage is for linear measurements (Fig. 5) and will accommodate films up to 28 × 12 cm in size. It can be moved in two directions at right angles on kinematically designed slides. For the measurement of linear distances on the films, a vernier is provided on the carriage and a 30 cm scale on the lower casting, enabling measurements to be made with an accuracy of 0·01 mm. In addition to this, a spring-loaded micrometer allows measurements to be made to 0·005 mm directly and 0·001 mm by nterpolation. This operates over a distance of 3 cm, and lso provides for fine movement of the film. Coarse adjust- ient is made by moving the whole carriage bodily on the nain slides (Fig. 3). Transverse movement of the film is ffected by a rack and pinion. The film itself is held down by ght spring clips on to a glass plate.

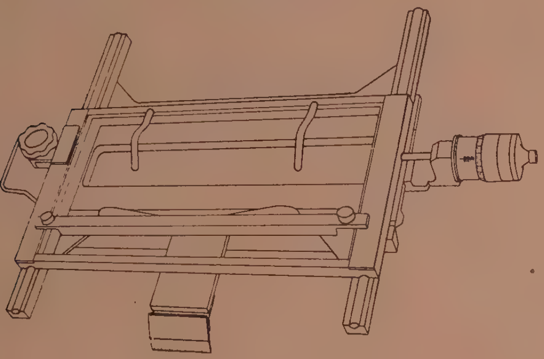


Fig. 5. Film carriage

While measurements are being made it is necessary to ave some means of illuminating the region of the film near ɔ the point under examination. This is done by a small pal glass screen lit from below by a flash-lamp bulb imme- iately behind the lower objective. This illuminates an area f about 1 in. square. The presence of this lamp does not ffect the instrument readings at densities below 2.

Access to the wedge and motor is made by means of a inged panel at the back of the instrument. A removable anel on top of the lower casting provides access to part of ıe electronic equipment allowing valves to be replaced vithout dismantling the whole instrument. The only controls n the instrument are three switches, the first controlling the nain supply, the second the motor and the third the film luminator.

(*c*) *Automatic balancing system.* The condition of balance obtained from the potential above earth of the wire joining ıe two photocells (point *G* on Fig. 1). The optical wedge driven to the balance point by a reversible induction motor ontrolled by relays. It is not generally realized that this ype of on-off servo, while of minimum complexity, is capable f a very useful performance if stabilized against the tendency ɔ oscillate.(3) The mains-driven motor, controlled by a air of Post Office type relays, has three possible states—full ower forward, zero power, full power reverse. The master ontrolling element is a centre-stable Carpenter relay governed the potential of point *G*. This arrangement has a small ead zone around the balance condition. This is unavoidable a discontinuous servo, since otherwise the motor would unt about the balance point indefinitely. Some hunting is kely, even when a dead zone is provided, because of the nstabilizing action of the circuit time delay and mechanical acklash. These may be overcome by applying negative elocity feedback, which effectively switches off the motor efore the balance point is actually reached. Ideally, a uare law negative velocity feedback is needed, but the roduction of the square law is somewhat elaborate and near negative velocity feedback is used in this instance, gether with some deliberately applied friction on the main mature shaft of the motor.

The photocell system is a very sensitive detector of light x unbalance. This is illustrated in Fig. 6, which shows the arked dependence of the voltage *e* upon the slope of the characteristics, for a given degree of light unbalance. When sufficient anode voltage is applied to a vacuum photocell the current approaches saturation and is then directly proportional to the incident light flux. In this condition the dynamic impedance becomes very large and therefore the slope becomes very small and the voltage *e* provides a sensitive indication of the light-flux balance condition. In practice it was found that a given density unbalance of $\pm 0{\cdot}005$ produced a reasonably constant unbalance voltage of ± 1 V at the common point of the photocells over the density range 0–3. This value is a reasonable dead zone and enables a straightforward d.c. measuring system to be used. Since the likely drift on the grid of the first valve over a period of hours is less than $0{\cdot}1$ V, the instrument can be expected to be extremely stable.

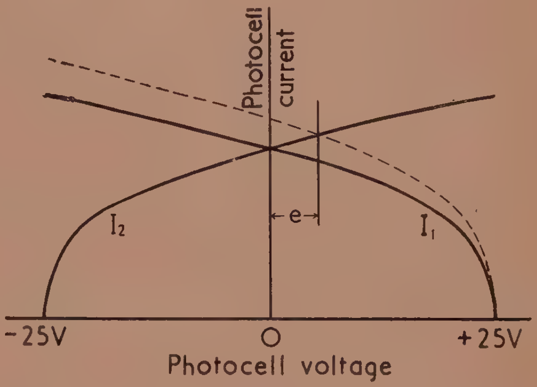


Fig. 6. Graphical construction of photocell system

The system has an inherent time lag owing to stray capacity to earth and the impedance of the photocells. At low levels of illumination, the latter may be so large that a time constant of the order of seconds may be produced. Such a long time delay in the servo-system constitutes a source of instability, and must be corrected. Fortunately, the effective stray capacity to earth can be reduced to less than 1% of its intrinsic value by means of a circuit device known as cathode-follower screening. The only part of the system of stray capacities which cannot be so reduced is the anode-cathode capacity of the photocells themselves. This capacity, however, is very small in the Cintel VA14 photocells used (manufactured by Cinema-Television Ltd.), in which the anode-cathode connexions are brought out on flexible leads from opposite ends of the cell. The photocells are mounted in an aluminium screening box which also carries the condensing objectives.

The cathode-follower valve is operated in a horizontal position with the top grid connexion entering the photocell screening box through a side aperture. The circuit diagram is shown in Fig. 7. The type EF37A valve (V_3) is chosen for a cathode follower because of its top connexion, and also because of its low grid current and operational stability with very high grid resistances. Half of the twin triode, V_{4a}, provides an effective load for the cathode follower V_3, while the other half V_{4b}, buffers the output voltage signal and feeds a resistance capacity differentiating network to provide the velocity feedback voltage. A sliding tap on the anode load of V_{4b} allows the degree of velocity feed-back to be pre-set to suit requirements. The twin triode V_5 operates the differential Carpenter polarized relay *via* its balanced pair of windings from the comparison of the output signal on V_{5a} and the reference signal on V_{5b}. The velocity feedback signal from the differentiating network is applied to the grid of V_{5b}. The Post Office relays switching the motor are controlled by the Carpenter relay *via* the buffer valve V_{6a} and V_{6b}, which is grid-switched by the Carpenter contacts in an obvious manner, the object being to avoid electrical wear of the Carpenter relay contacts. The 1 μF decoupling condensers C_8 and C_{10} on the anodes of V_{5a} and V_{5b} form a circuit with a time constant of one-hundredth of a second; this slows down the action of the Carpenter relay by a negligible amount as far as the servo-action is concerned, but enough to obviate two circuit difficulties. The first of these is due to ripple on the main light source which does not necessarily cancel out completely at the d.c. balance point. This remnant alternating signal, together with that caused by stray magnetic field modulation of the photocell current, can result in chatter of the relays if some smoothing is not introduced into the system. The second difficulty is due to a drop in the h.t. line voltage when the Post Office relays are activated. This may be passed on to the Carpenter relay if the pulse is not absorbed.

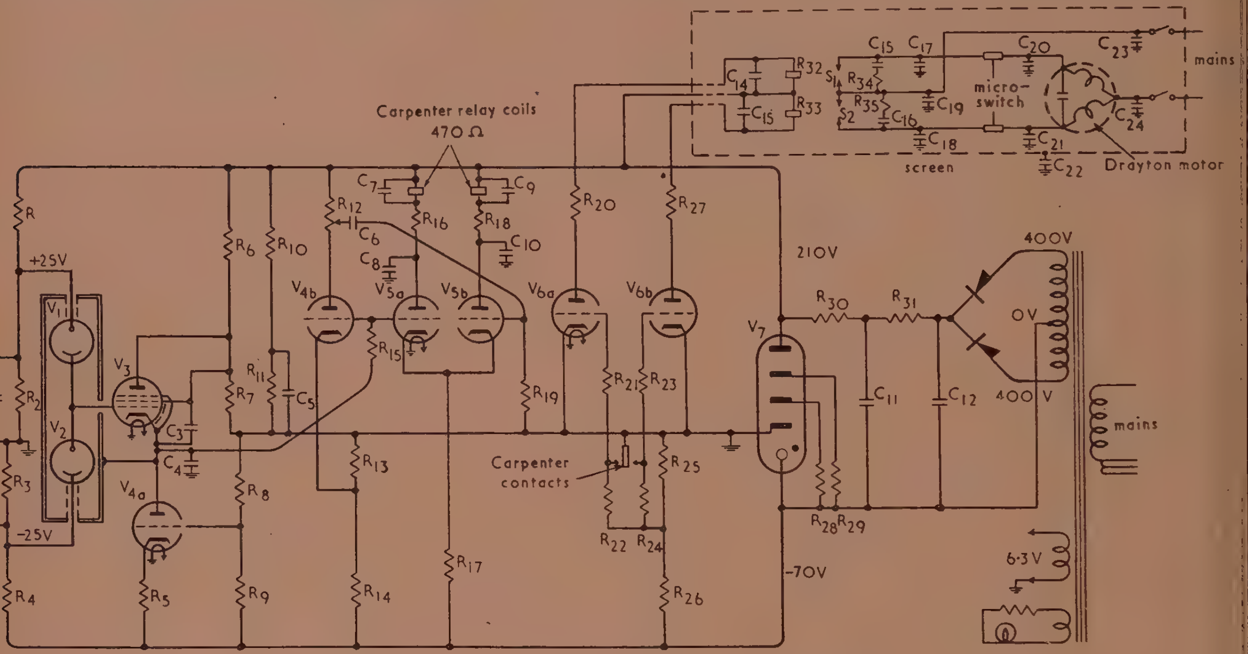


Fig. 7. Complete circuit diagram for the servo-control

R_1 = 680 kΩ
R_2, R_3 = 100 kΩ
R_4 = 150 kΩ
R_5 = 68 kΩ
R_6 = 680 kΩ
R_7 = 470 kΩ
R_8–R_{10} = 100 kΩ
R_{11} = 47 kΩ
R_{12} = 70 kΩ

R_{13} = 4·7 kΩ
R_{14} = 68 kΩ
R_{15} = 100 kΩ
R_{16} = 33 kΩ
R_{17} = 22 kΩ
R_{18} = 33 kΩ
R_{19} = 1 MΩ
R_{20} = 22 kΩ
R_{21}–R_{24} = 470 kΩ

R_{25} = 68 kΩ
R_{26} = 220 kΩ
R_{27} = 22 kΩ
R_{28}, R_{29} = 220 kΩ
R_{30} = 1 kΩ
R_{31} = 5 kΩ
R_{32}, R_{33} = 2 kΩ
R_{34}, R_{35} = 470 Ω

C_1 = 0·5 μF
C_2 = 0·5 μF
C_3 = 8 μF
C_4 = 0·05 μF
C_5 = 8 μF
C_6 = 0·02 μF
C_7 = 0·01 μF
C_8 = 1 μF

C_9 = 0·01 μF
C_{10} = 1 μF
C_{11} = 64 μF
C_{12} = 8 μF
C_{13}, C_{14} = 0·01 μF
C_{15}, C_{16} = 0·05 μF
C_{17}–C_{23} = 0·001 μF
C_{24} = 0·001 μF

V_1, V_2 = VA14
V_3 = EF37A
V_4 = ECC81
V_5, V_6 = ECC91
V_7 = STV280–40

There is one circuit difficulty which the motor system can introduce. Very short pulses produced by the motor switching can find their way to V_3 and produce short pulses of current. The rate of recovery of the grid potential is then governed by the time constant of the photocell circuit, and these interference pulses, enormously lengthened and always negative, can be intolerable. For this reason the motor and Post Office relays are placed as far as possible from the photocells. In addition, various points of the mains motor circuit are decoupled to earth with small condensers. The cathode of V_3 is also decoupled to earth since it is the main entry point of interference.

Special attention has been paid to the reliability of th circuit. Most of the valves are used simply as switches, and therefore have a long working life.

PERFORMANCE

The reproducibility of density determination was measure by repeated readings on a stepped calibration strip over th range 0–3. The standard error of density measurement wa 0·004, and was constant over the whole range. This repre sents an error of 0·4% at $D = 1$, 0·2% at $D = 2$ an 0·13% at $D = 3$. Normal levels of room lighting do n influence the readings of the instrument up to a density about 2. The warming up time is only that needed by th valve heaters. One possible source of error is the expansio of the lead screw during operation. The temperature rise the lead screw has been measured and amounts to abou 1°/hour. The error thus caused will be negligibly sma during normal running periods. The long term stability the instrument is quite satisfactory and no trouble has bee experienced during eighteen months of regular work.

There is no need to match the characteristics of the tw photocells, the only assumption made about them is that the current outputs should vary linearly with the light flu Vacuum photocells which run at low light intensities, suc as are found in the microdensitometer, obey this linear la very accurately. This result can be proved by analysis of th circuit, which shows that the unbalance voltage *e* produce when light fluxes I_1 and I_2 fall on the two photocells respe tively is given by:

$$e = [\rho_1\rho_2/(\rho_1 + \rho_2)](S_1I_1 - S_2I_2) \qquad (2$$

where ρ_1 and ρ_2 are the dynamic impedances of the two cells, S_1 and S_2 are the sensitivities in A/lm.

$$e = o \text{ when } S_1I_1 = S_2I_2 \qquad (3)$$

Balance is obtained when the light fluxes are in the ratio $_1/I_2 = S_2/S_1$, which is a constant if the cells are linear.

In practice, balance is obtained with no film in position, he revolution counter is set to zero, then with the film in position the new balance gives a true measure of the optical density of the film. The time taken to attain a balance automatically from zero density to a density of (say) 1 is 12 s, and for smaller changes correspondingly less. Should one photocell have to be replaced by another with different characteristics, the only adjustment necessary would be a esetting of the zero. In any case, this is always done when tarting a new set of readings. Should the dynamic impedance or sensitivity of either cell change while the measurements are being made, errors will result. These errors may be eliminated by frequent resetting of the zero point. In practice, uch changes are small, and the zero rarely varies by more han $D = 0{\cdot}004$, even after periods of about an hour. This s the normal error to be expected in any measurement.

The instrument could be made to record automatically by he use of a motor-driven film carriage and a potentiometric lide wire to denote the position of the wedge. In the present case such modifications were not deemed necessary. A wider range of image sizes on the film could be obtained by using an illuminated adjustable slit as the light source, although this would entail a considerable loss of light intensity. The present image size has been found adequate for Debye–Scherrer films.

One possible criticism of the instrument is that it compares the density of a photographic image with that of a colloidal graphite density wedge, the scattering characteristics of which are likely to be different. No difficulties have been experienced so far from this effect; the films used are linear up to a density of more than one. If very accurate work is required at higher densities, calibration of the film will avoid any error.

ACKNOWLEDGEMENTS

The authors are indebted to Mr. A. E. De Barr for initiating this work, and to Mr. W. F. Dorrell who constructed the mechanical parts of the instrument. They also wish to thank Dr. T. Emmerson, Director of Research of the G.K.N. Group Research Laboratory, for permission to publish.

Negotiations are being made with Chas. Cook and Sons Ltd. of Birmingham for the manufacture of this instrument.

REFERENCES

(1) Dobson, G. M. B. *Proc. Roy. Soc. A*, **54**, p. 248 (1923).
(2) Taylor, A. *J. Sci. Instrum.*, **28**, p. 200 (1951).
(3) Uttley, A. M. and Hammond, P. H. *Automatic and Manual Control.* Papers contributed to the Conference at Cranfield, 1951, edited by A. Tustin, p. 285 (London: Butterworths Scientific Publications, 1952).

An instrument for the accurate measurement of low optical densities*

By A. S. Cross, M.Sc., Grad.Inst.P., Research Laboratories, Kodak Ltd., Harrow, Middlesex

[*Paper received* 9 *July*, 1954]

An instrument for the measurement of photographic densities in the range 0 to 0·3 with reproducibility of 0·0001 is described, a greater range being obtainable at the expense of sensitivity. A balanced optical system is employed, modulation of the measuring beam being performed by polarizers. Barrier layer photocells and a galvanometer are used for balance indication.

The use of photographic plates coated with a single layer of ilver halide grains has recently received renewed attention.(1) The maximum density obtainable with these materials, however, is very low (usually about 0·2) and their use has been estricted by the inability of an ordinary densitometer to give ufficiently accurate readings; to plot their characteristic curves with an accuracy comparable with that obtained for normal photographic materials, a reproducibility of about 0·0002 is required. The instrument to be described was constructed several years ago to meet this need.

Recently the author's attention has been drawn to similar problems in autoradiography, in which the quantity of the sotope which can be taken up by a biological specimen is often restricted by the risk of radiation damage. In such cases the densities obtainable are frequently low, and accurate measurement is difficult; the instrument may thus have a wider range of application than was originally anticipated.

GENERAL PRINCIPLES

To obtain the required accuracy the instrument must be very stable, and for this reason a balanced optical system is used. Light from a lamp is passed through a modulator and the density to be measured on to a photocell; a comparison beam passes through a zero-setting wedge on to a second photocell. With no density in place the zero-setting wedge is adjusted until the photocells receive equal amounts of light. The density is then inserted and the modulator adjusted to re-establish balance, the adjustment necessary providing a measure of the density.

DETAILED DESCRIPTION

Method of modulation. In most instruments of similar type the modulator is calibrated experimentally. For the present purpose, however, it would not be possible to do this with the accuracy needed and it was necessary to choose a modulator which would allow readings to be taken according to a known law. To satisfy this requirement it was decided that modulation by two polarizers would be suitable, and that Polaroid filters would be convenient. The main source of error is in imperfections of the Polaroid; when the filters are "crossed" a certain amount of light is still transmitted. This causes an error in absolute accuracy; the change in illumination caused by rotation of one polarizer is less than the theoretical change and the measured density is thus too high. With the sample of Polaroid available the "crossed" transmission was 0·001, and the light transmitted was reasonably neutral. If a density of 0·3 is being measured this causes an error of 0·0004 in absolute accuracy, which was considered to be negligible. At higher densities this error becomes greater, but as the author was only interested in low densities the use of Polaroid was thus quite satisfactory.

---

* Kodak Communication No. 1669H.

In use, one polarizer is rotated from the "in-line" position until the change in density is greater than the density to be measured. For a density range of 0–0·3 it is convenient to set the axes of the polarizers at an angle $\theta_0 = 50°$. The zero is then set and the density to be measured is placed in position. After re-balancing by rotating the polarizer to the angle θ_D the density is given by

$$D = 2\,(\log \sec \theta_0 - \log \sec \theta_D).$$

From this relationship it is found that in order to obtain the required repetition accuracy θ should be read to 1′. This has been achieved by mounting the movable polarizer on a worm-driven turntable calibrated in degrees, the worm shaft rotating once per degree and carrying a drum divided into 5′ intervals. The scales can be set at the extinction angle (90°) with reasonable accuracy.

The density range can, of course, be increased by increasing θ_0. This reduces the total light transmitted and thus the sensitivity.

Optical system. The optical system is shown in Fig. 1. The measuring aperture has a diameter of 4 mm and is fitted with a cover-glass; this diameter can be reduced at the expense of sensitivity. The light transmitted by the density is collected by an opal cone in contact with it⁽²⁾ and falls on to the photocell in the measuring head. Light for the comparison photocell is reflected out of the main beam by a piece of plain glass.

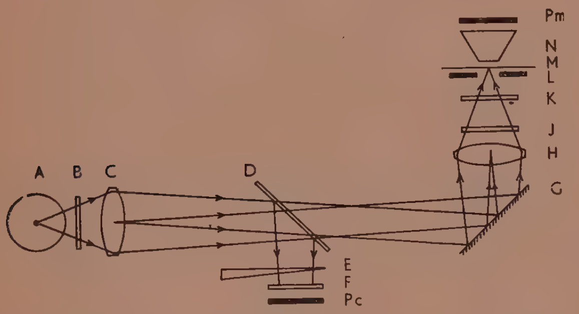


Fig. 1. Optical arrangement of low density densitometer

A, 6 V 30 W type F projector lamp; *B*, Chance ON 19 heat-absorbing glass; *C*, 4 cm *f*/2 lens; *D*, glass sheet; *E*, zero-setting wedge; *F*, opal glass; *G*, mirror; *H*, 4 cm *f*/2 lens; *J*, *K*, Polaroid sheets; *L*, measuring aperture; *M*, density to be measured; *N*, opal cone; *Pc*, *Pm*, comparison and measuring barrier layer photocells.

Photoelectric indication. For best stability extreme simplicity is desirable. The use of a matched pair of barrier layer photocells and a galvanometer has been found to be sufficiently sensitive, the circuit being as shown in Fig. 2. For rough balancing the sensitivity is such that a deflexion of 1 cm is obtained for a density change of 0·035; the sensitivity can be increased about fifteen times by closing the switch *S* shown in Fig. 2, enabling the final balance to be established to about 0·0001.

General construction. The optical components are mounted on a heavy brass framework attached to the underside of the lid of a box about 15 × 9 × 5 in. The external arrangement is shown in Fig. 3. The sensitivity and balancing controls are arranged at the user's left hand, leaving the right hand free for the more delicate tasks of manipulating the sample and recording results.

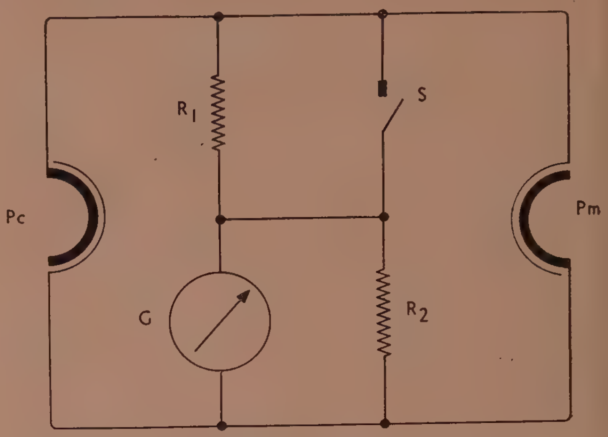


Fig. 2. Balance indicating circuit of low density densitometer

G = Cambridge spot galvanometer (450 Ω, 16 cm/μA); *Pc*, *Pm* = matched pair 1 in. diameter EEL photocells; $R_1 = 400$ kΩ, $R_2 = 33$ kΩ, *S* = sensitivity selecting switch.

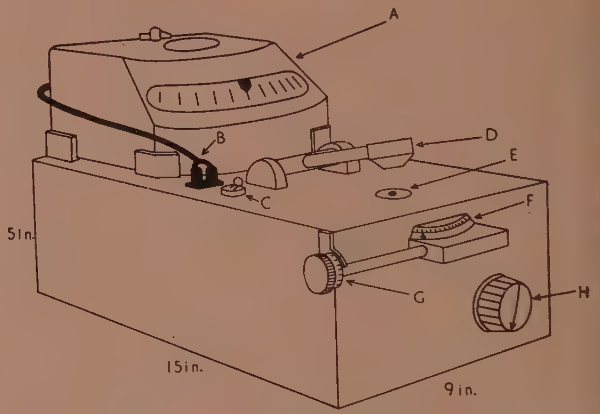


Fig. 3. External arrangement of low density densitometer

A, galvanometer; *B*, lead to galvanometer; *C*, sensitivity switch; *D*, measuring head; *E*, measuring aperture; *F*, turntable carrying degree scale; *G*, balancing control carrying scale in 5′ intervals; *H*, zero-setting control.

STABILITY

A change of 10% in supply voltage causes a zero shift of 0·001, presumably due to imperfect matching of the photocells. The use of a constant-voltage transformer reduces this figure to less than 0·0001. The maximum rate of drift in use is 0·002 per hour; thus for a reproducibility of 0·0002 the zero should be re-set every five minutes.

REFERENCES

(1) Stevens, G. W. W. *J. Photogr. Sci.*, **1**, p. 122 (1953).
(2) Owen, R. E., and Davies, E. R. *Photogr. J.*, **75**, p. 128 (1935).

A simple ratio-recording spectrometer

By N. H. E. Ahlers, B.Sc., A.Inst.P.,* and H. P. Freedman, Paint Research Station, Teddington, Middlesex

[*Paper received* 21 *September*, 1954]

A simple double-beam attachment for a single-beam infra-red spectrometer which can be built at little cost is described. No optical modification is needed and a minimum of additional electronic equipment is required for the existing instrument. The method employed is essentially an alternating beam system used in conjunction with a voltage ratio recorder. The beam splitter consists of a demountable twin cell arranged as a rotating sector wheel positioned in front of the entrance slit of the monochromator and is the only addition to the optical system.

he advantages of a double-beam infra-red spectrophoto- neter, recording directly in percentage transmission or ensity, are obvious when one considers the labour involved measuring energy curves with the customary "cell in—cell ut" technique and then carrying out the corresponding oint-by-point division necessary to obtain a spectrum of ercentage transmission *versus* wavelength. There are also he attendant difficulties arising from possible variations in ource intensity or in atmospheric absorption between two onsecutive records. An instrument which performs these unctions automatically must be capable of viewing the adiant energy passing through both the sample and the tandard cells simultaneously.

These requirements have been satisfactorily fulfilled by a umber of double-beam instruments described in the iterature.(1,2) However, it is true to say that the systems nvolved are either of special design in costly commercial pparatus or else have entailed expensive optical and elec- ronic modifications of single-beam instruments.(3,4)

The purpose of this paper is to describe a simple double- eam attachment(5) for a standard single-beam instrument model 12C by Perkin Elmer) which was built at little cost. No ptical modification was needed and a minimum of additional lectronic equipment was required for the existing apparatus. he method employed is essentially an alternating beam ystem used in conjunction with a voltage ratio recorder.

METHOD

The system adopted is illustrated by the block diagram hown in Fig. 1. The components outlined in full in the iagram are typical of the general arrangements of a single- eam infra-red spectrometer. Certain additional components hown, e.g. beam splitter, are the customary units incorporated or double-beam operation. Thus with two radiation signals, he introduction of a further filter and the modification of the recorder to ratio operation are required. The auxiliary amplifier, while not an essential addition, features in the method for reasons of convenience which will be explained later.

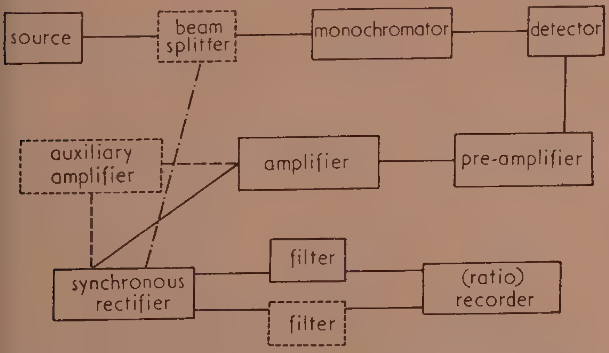


Fig. 1. Block diagram of a double-beam infra-red spectrophotometer

The system employed is double-beam in time only with one radiation beam from the Globar source which travels alternately through the control and sample cell. In some arrangements(3,6) the radiation is alternated by a rotating mirror system. In the present method, however, the radiation from the source is not diverted and the cells are alternatively at the same position, in the path of the beam.

The essence of the method is the rotating cell assembly and the associated contactor system shown in Fig. 2. In this photograph the rotating cell assembly is shown in position in front of the entrance slit of the Perkin Elmer (model 12C) monochromator, together with the associated contactor system. The small metal housing of the instrument has been removed for convenience, exposing the Globar source and focusing mirrors. The standard radiation chopper motor and its associated assembly may also be seen.

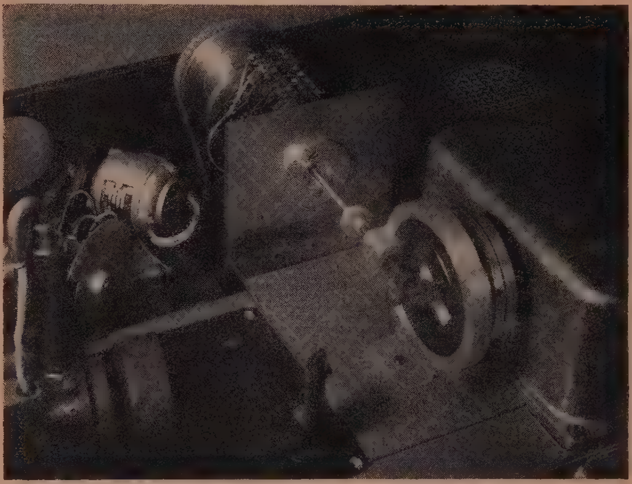


Fig. 2. Rotating cell assembly and synchronous contactor system positioned in instrument

In Fig. 3 the slit side of the clamping plate of the twin cell unit *D* is shown. This is divided into four sectors, each occupying 90° of rotation. Two of these sectors are provided with the rocksalt windows and form the cells while the intervening ones are opaque and act as shutters. Consequently as the twin cell assembly rotates the radiation beam will be interrupted, in the following sequence:

(1) by the control cell giving the 100% transmission level ($\frac{1}{26}$ sec);
(2) by the metal sector giving a zero level ($\frac{1}{26}$ sec);
(3) by the sample cell giving the level to be recorded ($\frac{1}{26}$ sec);

---

* Now at Unicam Instruments Ltd., Cambridge.

(4) by the second metal sector also giving a zero level ($\frac{1}{26}$ sec).

The waveform of the light output to the detector is thus a square wave at 13 c/s, successive cycles representing the transmissions through the control and sample cells respectively.

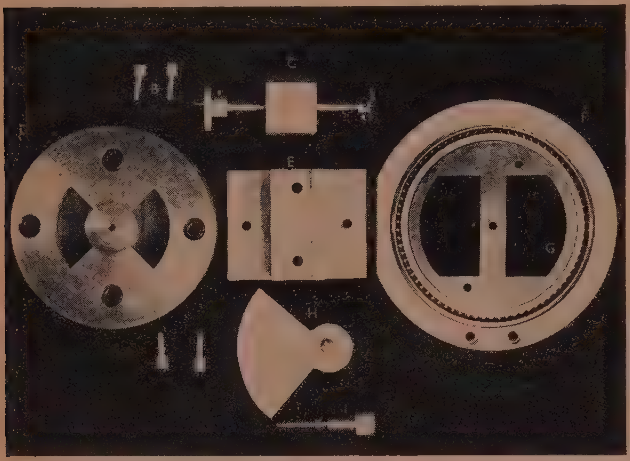


Fig. 3. Component parts of rotating cell assembly

B, cell filler plugs; *C*, drive shaft assembly; *D*, twin cell unit; *E*, cell unit base; *F*, outer bearing housing; *G*, cell carrier plate; *H*, shutter; *I*, cell retaining screw.

The electrical output from the detector is amplified, and after separation in the contactor assembly, provides two voltages each proportional to the transmission of one cell. These are applied to a modified Brown recorder, producing a ratio record of spectral transmission.

ROTATING CELL ASSEMBLY

The component parts of this assembly are shown in Fig. 3. The twin cell unit *D* is located on the cell carrier plate *G* by two dowel pins and attached by means of the single central fixing screw *I*. To avoid excessive blocking of the radiation beam by mechanical parts the cell carrier plate is fitted with an external ring bearing *F* and is rotated from the shaft of the contactor assembly by means of small bevel gears as shown in Fig. 2. A simple dog-coupling on the drive shaft *C* allows the whole cell assembly to be readily removed for single-beam operation of the instrument.

TWIN CELL UNIT

The construction of one cell of this unit is shown in Fig. 4. The rocksalt windows *B*, separated by a lead spacer *A* of the appropriate thickness, are mounted as two pairs diametrically opposite in the single centre plate *C* and form the twin cell unit. The windows themselves are carefully selected in pairs of nearly equal thickness to minimize the possibility of fracture. The centre plate and cells are located between the two outer clamping plates *D* by means of four Allen screws, an effective seal being provided by the sealing gaskets *E*. A third accommodating washer *F* allows some latitude in the thickness of the window-spacer sandwich and enables the same centre plate to be used for a variety of path lengths. Each cell is provided with two tapered holes through which the cells may be filled with a syringe without the inclusion of air bubbles. Closure is effected by tapered steel plugs *B* shown in Fig. 3.

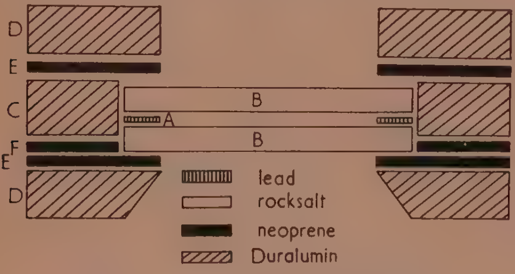


Fig. 4. Cell constructional details

A, lead spacer; *B*, rocksalt plates; *C*, centre plate; *D*, clamping plates; *E*, scaling gaskets; *F*, accommodating washer.

SYNCHRONOUS CONTACTOR ASSEMBLY

There are eight pairs of contacts (one fixed and one moving) in the assembly and four pairs are visible in Fig. 5, while the others, mounted 180° out of phase, are concealed on the reverse side. Four pairs are used for signal rectification and separation as described above, and two pairs for the provision of test signals in phase with the input from the detector. The additional pairs are superfluous having originally been introduced for a modification which later proved unnecessary.

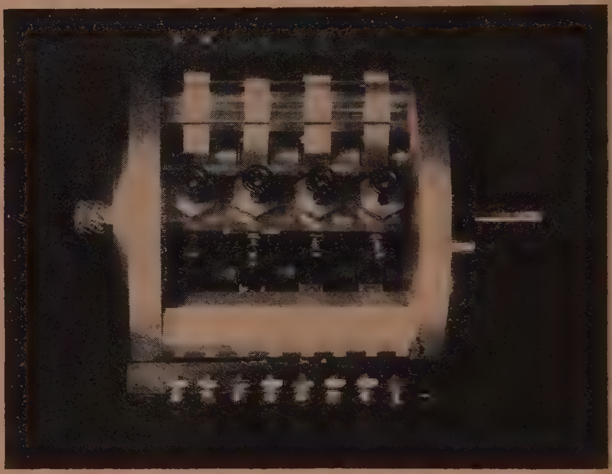


Fig. 5. Synchronous contactor assembly

The contacts are, in fact, a standard type of car ignition component, and, as such, are used without modification. Their movements are controlled by eccentrics mounted on the shaft driving the rotating cell assembly. The eccentrics are made of lengths of silver steel (1 in. diameter) and are mounted $\frac{1}{16}$ in. off-centre on the drive shaft. The followers are made of Tufnol and at the relatively low speed of operation very little wear is anticipated.

Adjustment. The setting of contact time is readily effected by movement of the fixed contacts while phase adjustment is achieved by rotation of the eccentrics relative to the drive shaft. Contact pressure is fixed by the conventional springs. Finally the whole assembly is capable of rotation to allow for cell phasing adjustment.

Intermodulation effects. Interaction of the two beams is found to occur arising from the frequency response of the detector and amplifier and, in particular, from the capacity tuned input and output transformers of the amplifiers.

The waveform of the light output to the detector approximates to a square wave, at 13 c/s, amplitude modulated by a second square wave of half the frequency. The response to the 6·5 c/s component (and to its odd harmonics) is less than that to the corresponding 13 c/s components. Consequently, the effective depth of modulation is decreased and the output with respect to each "beam" contains a proportion due to the other "beam."

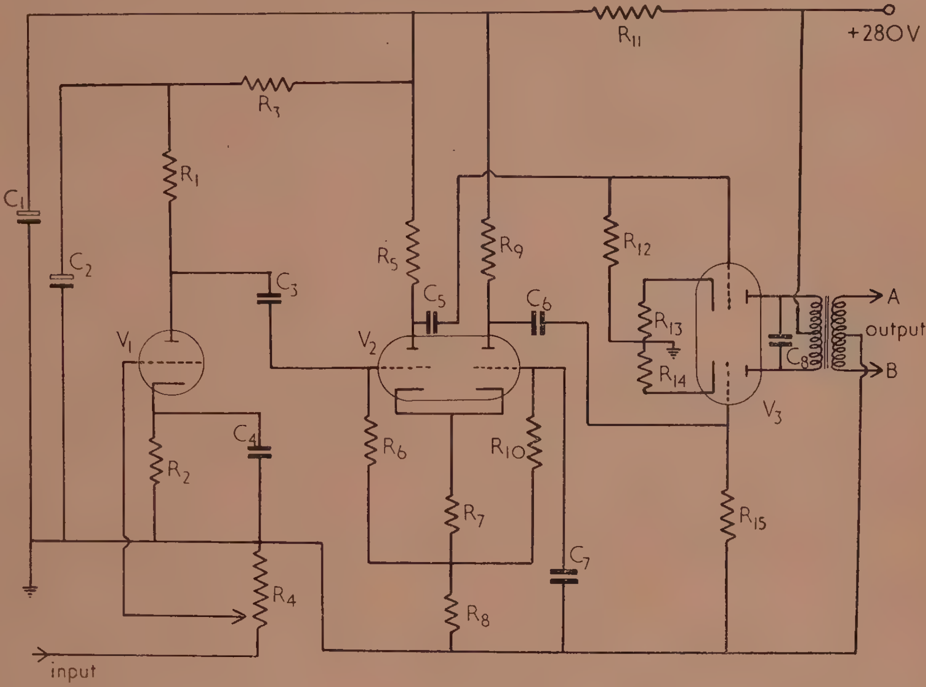

R11
+280V
R3
R1
C1
C2
C3
R5
R9
R12
C5
C6
R13
R14
A
output
B
C8
V1
V2
V3
C4
R2
R6
R10
R7
R15
C7
R4
R8
input

Fig. 6. Circuit diagram of auxiliary amplifier

$R_1 = 100$ kΩ
$R_2 = 1$ kΩ
$R_3 = 50$ kΩ
R_4, $R_5 = 100$ kΩ
$R_6 = 1{\cdot}5$ μΩ
$R_7 = 900$ Ω
$R_8 = 22$ kΩ
$R_9 = 100$ kΩ
$R_{10} = 1{\cdot}5$ MΩ
$R_{11} = 20$ kΩ
$R_{12} = 1{\cdot}5$ MΩ
R_{13}, $R_{14} = 1$ kΩ
R_{15} 1·5 MΩ

C_1,·C_2 16 μF
$C_3 = 1$ μF
$C_4 = 25$ μF
C_5–$C_8 = 1$ μF

$V_1 = $ 6J5
V_2, $V_3 = $ 6SN7

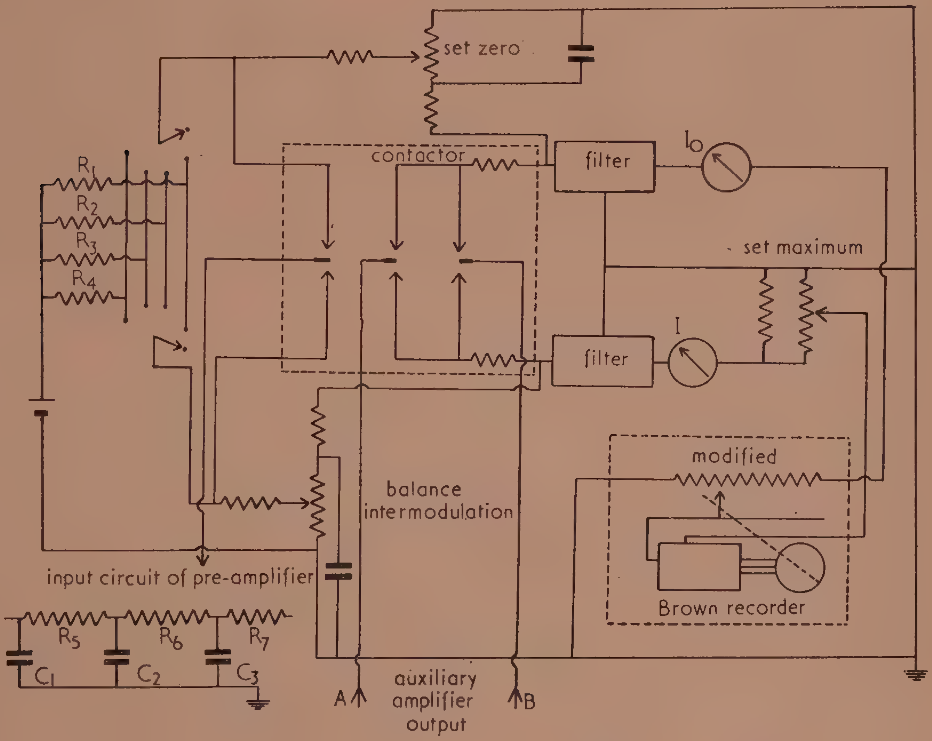

set zero
contactor
filter
I0
set maximum
R1
R2
R3
R4
I
filter
modified
balance
intermodulation
Brown recorder
input circuit of pre-amplifier
R5
R6
R7
C1
C2
C3
A
auxiliary
amplifier
output
B

Fig. 7. Simplified circuit diagram of complete system

$R_1 = 500$ Ω
$R_2 = 5$ kΩ
$R_3 = 50$ kΩ
$R_4 = 500$ Ω
R_5, $R_6 = 1$ kΩ
$R_7 = 600$ Ω

$C_1 = 500$ μF
C_2, $C_3 = 350$ μF

To combat this effect, a proportion of the d.c. output of each "beam" is fed back to the input, in antiphase to the effective signal due to inter-modulation.

ELECTRONIC ARRANGEMENTS

As stated earlier, an auxiliary amplifier has been incorporated in the modification and the circuit diagram is shown in Fig. 6. Connexion is made to the output stage of the model 83 Perkin Elmer amplifier, by the provision of a switch substituting the auxiliary amplifier for the normal para-fed output transformer. This unit, which is conventional in design, is used only as a power amplifier, to prevent overloading of the output stages of the standard model 83 amplifier. The voltage gain needed is such that the first triode stage is not essential.

In Fig. 7 the remainder of the electrical system is shown. The filters for removing the a.c. components of the outputs have time constants such that the response is approximately 99% in 20 sec. This delay is inherent in the method as the effective input to the filter is at half the previous frequency and because the recorder will respond to the 6·5 c/s ripple. Recording time must therefore be increased to achieve maximum effective resolution.

RECORDER MODIFICATIONS

The Brown self-balancing potentiometric pen recorder of 10 mV full scale deflexion is the standard recorder for the Perkin Elmer infra-red spectrometer and this instrument has been retained. However, to avoid switching in the measuring circuit an additional circular slide-wire for ratio operation has been incorporated. This is conveniently accommodated inside the recorder behind the existing mechanism. As a ratio recorder it functions satisfactorily over a 4 : 1 input level range. The existing Perkin Elmer string slit drive has been found adequate to maintain the signal limit within these limits.

OPERATION AND PERFORMANCE

The method of operation of the modified instrument for double-beam recording is both simple and straightforward. Furthermore, the change from double- to single-beam operation or *vice versa* is readily effected. For double-beam working initially *both* cells of the rotating twin cell unit are filled with the solvent to be used, generally carbon tetrachloride or carbon disulphide, care being taken to avoid the inclusion of air bubbles. The unit is then attached to the cell carrier plate, and the cells blanked off in turn with the metal shutter, the output being balanced to zero by the appropriate "balance intermodulation" or "set zero" control. The 100% level setting is made with both cells unmasked. The *I* cell is then emptied of solvent and filled with a solution of the sample under investigation and the spectrum recorded. (All adjustments are conveniently made with controls on the auxiliary amplifier.)

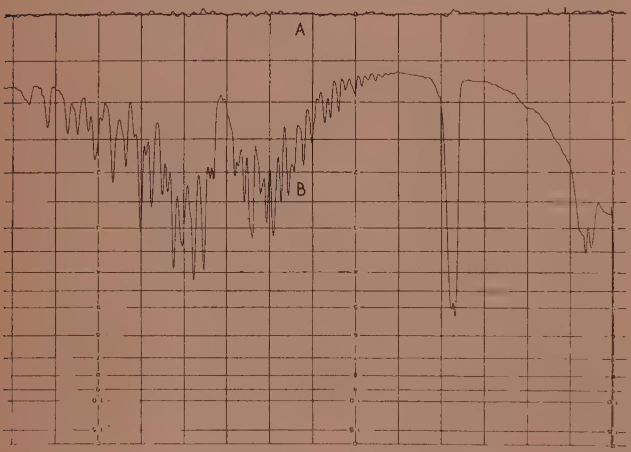


Fig. 8. Instrument records

Atmospheric absorption (2–8 μ) (rocksalt prism, slit drive). *A*, double beam (100% level); *B*, single beam

The system has been in operation for about two years, during which time it has given satisfactory and reliable performance. An example of the double-beam operation is shown by the instrument records of Fig. 8. In these measurements the 100% transmission level made with empty cells at a customary single-beam speed is shown recorded over the wavelength 2–8 μ. The slight deviations from the 100% line are due to the delay in the intermodulation compensation and correspond to the severe atmospheric absorption bands shown in the single-beam record.

The general performance of the method may also be judged from Fig. 9 which shows the instrument record of the infra-red spectrum of benzene recorded over the wavelength range 2–8 μ in a 100 μ cell. Some idea of the reproducibility of the method is given by a repeat record over the first measurement. Up to the present, measurements have been limited to the use of liquid cells of up to 1 cm thickness.

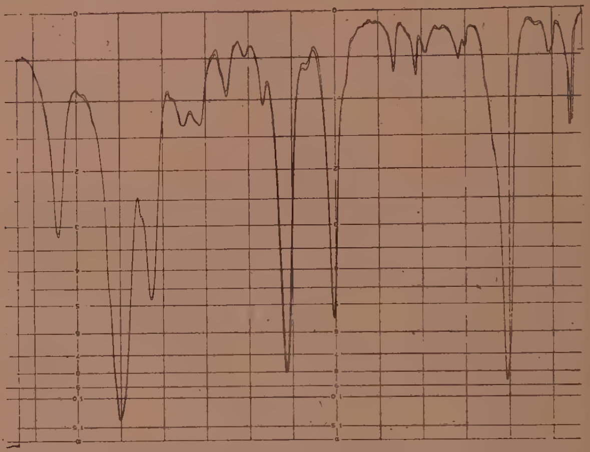


Fig. 9. Double beam infra-red spectrum of benzene (2–8 μ) (record and repeat)

In conclusion it should be pointed out that the rotating twin cell method for double-beam operation could lend itself to application in both visible and ultra-violet spectroscopy.

ACKNOWLEDGEMENTS

The authors wish to thank the Council and Director of the Research Association of British Paint, Colour and Varnish manufacturers for permission to publish this paper. Acknowledgement is also made to Mr. E. W. M. Fawcett for his advice and guidance during the carrying out of this work at the Paint Research Station.

REFERENCES

(1) Liston, M. D., and White, J. U. *Analyt. Chem.* **20**, p. 1127 (1948).

(2) Baird, W. S., and O'Bryan, H. M. *J. Opt. Soc. Amer.*, **37**, p. 754 (1947).

(3) Hornig, D. F., Hyde, G. E., and Adcock, N. A. *J. Opt. Soc. Amer.*, **40**, p. 497 (1950).

(4) Wright, N., and Hersher, R. *J. Opt. Soc. Amer.*, **37**, p. 211 (1947).

(5) Ahlers, N. H. E., and Freedman, H. P. *Nature* [*London*], **172**, p. 260 (1953).

(6) Hales, J. L. *J. Sci. Instrum.*, **30**, p. 52 (1953).

The stability of the calibration of liquid sample Geiger–Müller counter tubes

By N. Veall, B.Sc., F.Inst.P.,* and A. E. Lowe,† Medical Research Council, Radiotherapeutic Research Unit, Hammersmith Hospital, London, and R. E. Whyard, B.Sc., Electronics Division, Atomic Energy Research Establishment, Harwell

[*Paper received* 20 *October*, 1954]

It is possible to construct equipment for the automatic counting of radioactive samples in solution by placing each sample in a different counter tube of the liquid sample type (CV2145) and switching to each tube in turn. The day-to-day variation of the calibration factor of such tubes, which is the main source of error in the method, is found to be $\pm 0 \cdot 6\%$. Background errors due to γ-radiation from samples in adjacent tubes are reduced to less than $0 \cdot 1\%$ by suitable lead shielding. The results are also relevant to the use of liquid sample counters as calibrated secondary standards for the absolute assay of radioactive isotopes.

The counting of radioactive samples in solid form with the aid of equipment which presents a series of planchets in turn to a counter and automatically records their activity is now a well-established procedure.(1) However, there are numerous applications of radioactive tracers where the samples may be more conveniently and more accurately measured as a solution. The design of an automatic sample changer to deal with such samples presents considerable difficulties, particularly if the volume of solution available is limited, and it is necessary to devise a means whereby the counter assembly is cleaned and dried between samples.

The CV2145 counter tube (e.g. type M6 by 20th Century Electronics Ltd.) is widely used for the measurement of liquid samples.(2) It is possible, in principle, to use this type of counter tube for automatic counting by placing each sample in a different counter tube and arranging for control gear to switch to each counter in turn. The factors which limit the accuracy of this procedure are:

(1) since different counter tubes have different sensitivities for a given isotope, it is necessary to determine the relative sensitivity of each tube and assume that the calibration factor so obtained remains constant;
(2) in the case of γ-emitting isotopes, it is necessary to ensure that the background of any particular counter is not affected appreciably by the presence of radioactive samples in the other counters.

An apparatus has been constructed which can take up to thirty samples and the present report gives the results of tests undertaken to determine whether or not the above factors introduce appreciable errors.

CONTROL EQUIPMENT

Automatic counting equipment, shown schematically in Fig. 1, was developed to control the apparatus. The operational sequence followed in making the measurements is determined by a control unit which may be arranged either to make, successively, timed counts on any number of samples up to a maximum of thirty, or to give repeated timed counts on any one sample. Measurements on a number of samples are made in cyclic order starting with sample No. 1, and may be stopped when the required number of samples have been counted, or allowed to continue in reverse order back to sample No. 1. Facilities exist for interrupting this cycle of operations to make a timed-count on any one selected sample out of turn. One measurement is made on the selected sample and then the normal cycle is continued.

The counters are connected to a probe unit type 1014A and the e.h.t. supply unit, type 1112A, by a switching mechanism consisting of a set of high voltage relays operated by the control unit. Pulses from the probe unit are fed to a scaling unit type 1130 and are counted during the timed-count periods. An output pulse is forwarded to the count accumulator for every 1000 pulses counted by the scaler.

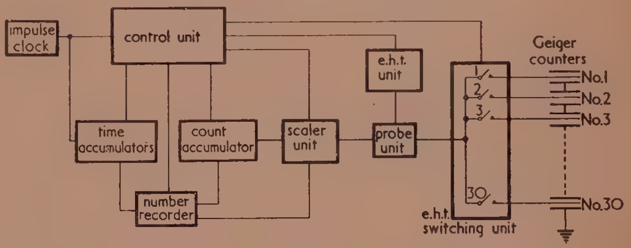


Fig. 1. Automatic counting equipment (schematic)

Timing signals are obtained from an impulse clock (type 30 by Magenta Time Co.) and are stored in the time accumulators, one of which registers the total time in minutes from starting the equipment, and the other the duration of each timed-count period. The latter is reset to zero as each new sample is selected. The equipment may be either time or count controlled, depending on the setting of the time and count limit switches.

On completion of each timed count a number recorder type 1061A is used to record:

(1) the time at which the measurement was completed (reckoned in minutes from starting the equipment);
(2) the sample number;
(3) the number of counts registered;
(4) the time of the counting period in minutes.

In the calibration tests reported below, the equipment was operated in the count controlled condition so that each measurement was completed at the end of the minute during which the 40 000th count occurred. Complete forward and reverse cycles of measurements were made using a total of thirty counters. With this system, the arithmetic mean of each pair of measurements gives the counting rate of the sample corresponding with the time at which reverse cycle of counting was commenced, so that it was not necessary to make decay corrections with the ^{131}I samples used.

LEAD SHIELDING

The arrangement of the lead castles which was adopted is shown in Fig. 2. This arrangement represents the best compromise between a number of requirements, some of which are conflicting. These are:

---

* Now at Guy's Hospital Medical School, London.
† Now at Experimental Radiopathology Research Unit, Hammersmith Hospital, London.

(1) each counter tube to have 5 cm of lead shielding from external radiation;
(2) adequate shielding between adjacent counter tubes;
(3) minimum requirement for space;
(4) minimum quantity of lead and lowest cost of fabrication.

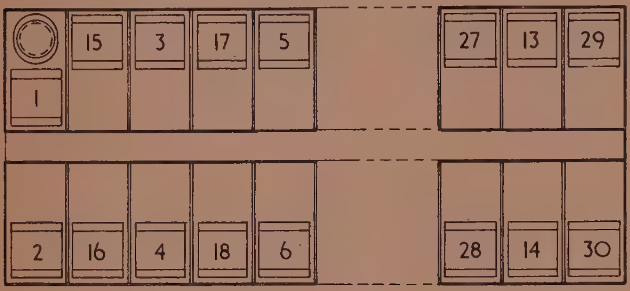


Fig. 2. Arrangement of lead castles

A unit lead castle was designed, and a set of thirty were manufactured by the E.R.D. Engineering Co. These were arranged in two rows as shown (Fig. 2) and 2·5 cm thick lead shielding plates were fitted to the end castles. There was 1 in. of lead shielding between adjacent counter tubes.

Interference tests were carried out with three representative γ-ray emitting isotopes. Assuming that all the counter tubes are filled with the same strength of solution, the increase in counting rate from a tube in the middle of a row due to the other samples is as follows:

(*a*) ^{24}Na (hard β, hard γ)—0·6%;
(*b*) ^{131}I (moderate β, soft γ)—0·05%;
(*c*) ^{60}Co (soft β, hard γ)—2·8%.

It follows, therefore, that this arrangement does not provide adequate shielding for such isotopes as ^{60}Co or ^{59}Fe. On the other hand removal of the adjacent counters on either side reduces the interference in all cases to less than 0·03%. For this reason, the castles are arranged in the order shown. Thus, rather than provide the extra lead necessary to meet all cases, it appears more economical to use only castles (1) to (14) with the few isotopes where the above shielding is inadequate.

The question of interference from adjacent samples does not, of course, arise in the case of pure β-emitters such as ^{32}P.

STABILITY OF COUNTER TUBE CALIBRATION

Small-scale tests carried out some years ago on type M6 counter tubes of the original type (graphite cathode, argon-alcohol filling) indicated that the absolute sensitivity of a tube might vary from day to day by about ±2%. More recently, the type M6M tube (by 20th Century Electronics Ltd.), having a stainless steel cathode and argon-ethyl formate filling, has become available, and this type of tube was chosen for test purposes.

Since the same e.h.t. voltage is applied to all the counters it was necessary to select a group of counters having approximately the same working voltage. Twenty-eight tubes, the threshold voltages of which fell within ±30 V of the mean value for the group (910 V), were tested. The tests were carried out with the e.h.t. voltage set at 1000 V.

A solution of ^{131}I was prepared, and each tube filled with the same solution. Rubber caps were placed over the tubes to prevent changes in ^{131}I concentration due to evaporation losses. A series of twenty-five readings was made, over a period of about three weeks, a reading consisting of two observations, each totalling 40000 counts. The counting rates ranged from about 8000 to 1000 counts per minute during the tests. All measurements were corrected for background and for the resolving time of the probe unit.

The table shows the mean calibration figure for ^{131}I for each counter tested, in counts per min per μC per l., together with the percentage root mean square deviation derived from twenty-five observations.

Sensitivity of M6M counter tubes for ^{131}I solution, and observed day-to-day variation of sensitivity

Counter No.	Sensitivity (counts per min per μC per l.)	σ r.m.s. deviation % $n = 25$	Counter No.	Sensitivity	σ
1	249·1	0·43	15	195·1	0·74
2	240·3	0·56	16	193·5	0·66
3	238·8	0·65	17	191·0	0·75
4	229·9	0·83	18	178·8	0·51
5	225·4	0·56	19	170·9	0·63
6	223·5	0·77	20	169·5	0·61
7	212·4	0·78	21	165·9	0·67
8	208·2	0·73	22	163·9	0·54
9	209·1	0·55	23	164·0	0·62
10	205·6	0·73	24	159·7	0·66
11	203·2	0·62	25	140·8	0·91
12	198·1	0·76	26	134·0	0·51
13	198·4	0·61	27	132·5	0·84
14	196·1	0·91	28	124·8	0·86

DISCUSSION

The average day-to-day variation in the absolute calibration of the twenty-eight counters tested was found to be 0·68% ± 0·12%. As the measurements were based on 80000 counts involving a statistical error of ±0·35% the fluctuations due to other causes reduce to ±0·58%. This figure includes any changes due to variations in e.h.t. voltage as well as changes due inherently to the counter tube. It follows therefore that the comparison of radioactive samples in different counters does not introduce any errors which are likely to be regarded as serious for any practical application, and that the design of automatic counting apparatus working on this principle is a feasible proposition. There will, of course, be a considerable amount of latitude in the design of such an apparatus, both as regards number of samples and the type of controlling gear, depending on requirements.

The stability of the calibration of liquid sample Geiger–Müller tubes is also of importance in connexion with their use as calibrated substandards for the absolute assay of radioactive solutions on a routine basis.(3) Miss A. M. Wildblood has tested the long-term stability of the type M6H tube (stainless steel cathode, halogen quenching) using ^{60}Co solution to confirm their suitability for this purpose. The results obtained indicate that the M6H tube should also be satisfactory for automatic liquid sample counting equipment.

REFERENCES

(1) Peacock, W. C., Evans, R. D., Irvine, J. W., Good, W. M., Kip, A. F., Weiss, S., and Gibson, J. G. *J. Clin. Invest.*, **25**, p. 605 (1946).
(2) Veall, N. *Brit. J. Radiol.*, **21**, p. 347 (1948).
(3) Putman, J. L. *Brit. J. Radiol.*, **23**, p. 46 (1950).
(4) Wildblood, A. M. Private communication.

A tuned detector-amplifier for power-frequency measurements

By W. K. Clothier, B.Sc., M.E., A.Inst.P., and W. E. Smith, B.Sc., Commonwealth Scientific and Industrial Research Organization, National Standards Laboratory, Chippendale, New South Wales, Australia

[*Paper first received* 22 *September, and in final form* 29 *October*, 1954]

A tuned detector-amplifier for power frequencies (20–60 c/s) is described. It can detect $\frac{1}{4}\,\mu$V in a 1 MΩ resistance source and when used with suitable tuned input transformers, its power sensitivity is 10^{-19} W. The amplifier is tuned by means of a two-section inductance-capacitance filter, the inductors of which are varied simultaneously by a direct current in control windings on their Mumetal cores.

The advantages of electronic detectors for bridge measurements at low frequencies are well known, and several have been described.(1–4) Looms(4) has compared this type of detector with the vibration galvanometer and has pointed out the limitations of the latter instrument arising from the sharply-resonant properties of its moving system and from its susceptibility to damage through overload. In order to serve as an effective substitute for the vibration galvanometer the electronic detector must be provided with at least some measure of tuning, but there are many applications, particularly in measurements using frequency dependent bridges, in which adequate selectivity cannot be achieved in a single stage of tuning except at the cost of extreme sensitivity of the gain to small frequency changes together with sluggish response to amplitude changes—effects familiar to anyone who has worked with a lightly-damped vibration galvanometer. These effects can be avoided by employing two or more low-selectivity filters in cascade and the electronic detector lends itself fairly readily to this form of construction. Tuning may be controlled over a continuous range by means of ganged variable resistors or air capacitors in, for example, a parallel-T or similar resistance-capacitance feedback filter network. However, these filters tend to become electrically and mechanically complicated when more than a single filter stage is used.

The electronic detector described below avoids these difficulties by using a passive two-section band-pass filter tuned by means of saturable core inductors which are "ganged" simply by connecting their saturating windings in series. The detector can be tuned over a continuous range from 20 to 60 c/s. It was developed as a general purpose power-frequency detector and is suitable for use down to signal levels, limited only by the Johnson noise in the supply circuit and the shot and flicker noise inherent in the first amplifying stage.

By means of suitable tuned input transformers the amplifier can be matched to the signal source without significant increase in noise power. The performance of transformer and amplifier is then best stated in terms of the power sensitivity which is such that 10^{-19} W can be detected provided that the transformer is adequately shielded from magnetic fields and from mechanical vibration and shock. This performance is considerably better than that of the best vibration galvanometers.

GENERAL DESCRIPTION OF AMPLIFIER

The amplifier comprises two triode amplifying stages, V_1 and V_2 (Fig. 1), a cathode-follower V_3 supplying an inductance-tuned two-section filter, and a triode output stage V_4. The Mumetal cored inductors L_p and L_s of the filter are tuned by means of direct current flowing in series-connected saturating windings. Gain is controlled by means of a stepped attenuator at the input of the amplifier and a continuously variable attenuator preceding the cathode follower V_3. The output is applied to an electron-ray indicator V_8 and also is available for connexion to an external cathode-ray oscilloscope. When the amplifier is used untuned, the cathode-follower stage is converted to a normal amplifying stage with an anode load circuit such as to give the same gain as the filter stage.

DETAILED DESCRIPTION

The filter. The filter may be represented by the equivalent circuit of Fig. 2 comprising two series-resonant circuits coupled together by the capacitor C_n and tuned by the variable inductors L_p and L_s. The primary circuit consists of the generator resistance R_g, the primary inductance L_p with its associated loss resistance R_a, and the capacitors C_a and C_n in series. The secondary circuit consists of C_b and C_n in series together with the secondary inductance L_s and loss resistance R_s. A closer approximation to the real filter would include shunt resistors in parallel with the inductors in order to represent eddy-current losses in the core material, but the equivalent circuit of Fig. 2 is sufficient for gauging the general behaviour of the filter. Analysis of the filter(5) for the case where $C_a = C_b = C_0$ and $L_p = L_s = L$, shows that the output voltage V_0 in terms of the input voltage V_i is given by

$$\left|\frac{V_o}{V_i}\right| = \left\{\omega^2 C_n C_0 R_p R_s \sqrt{\left[\left(1+\frac{1}{\omega^2 C_n^2 R_p R_s}-\frac{X^2}{R_p R_s}\right)^2 + X^2\left(\frac{R_p+R_s}{R_p R_s}\right)^2\right]}\right\}^{-1} \quad (1)$$

where

$$R_p = R_a + R_g$$
$$X = \omega L - 1/\omega C$$
$$C = C_0 C_n/(C_0 + C_n)$$

This response is unsymmetrical about the resonant frequency, the effect of the asymmetry being to increase the attenuation at harmonic frequencies, a useful property in a filter the primary purpose of which is to remove unwanted components of the bridge supply frequency.

The coefficient of coupling, k, can be found from

$$k = C/C_n \quad (2)$$

and critical coupling occurs when

$$k = 1/\sqrt{(Q_p Q_s)} \quad (3)$$

where Q_p, Q_s are the Q-factors of the primary and secondary circuits considered separately. By making the coupling critical, or somewhat greater than critical, a band-pass

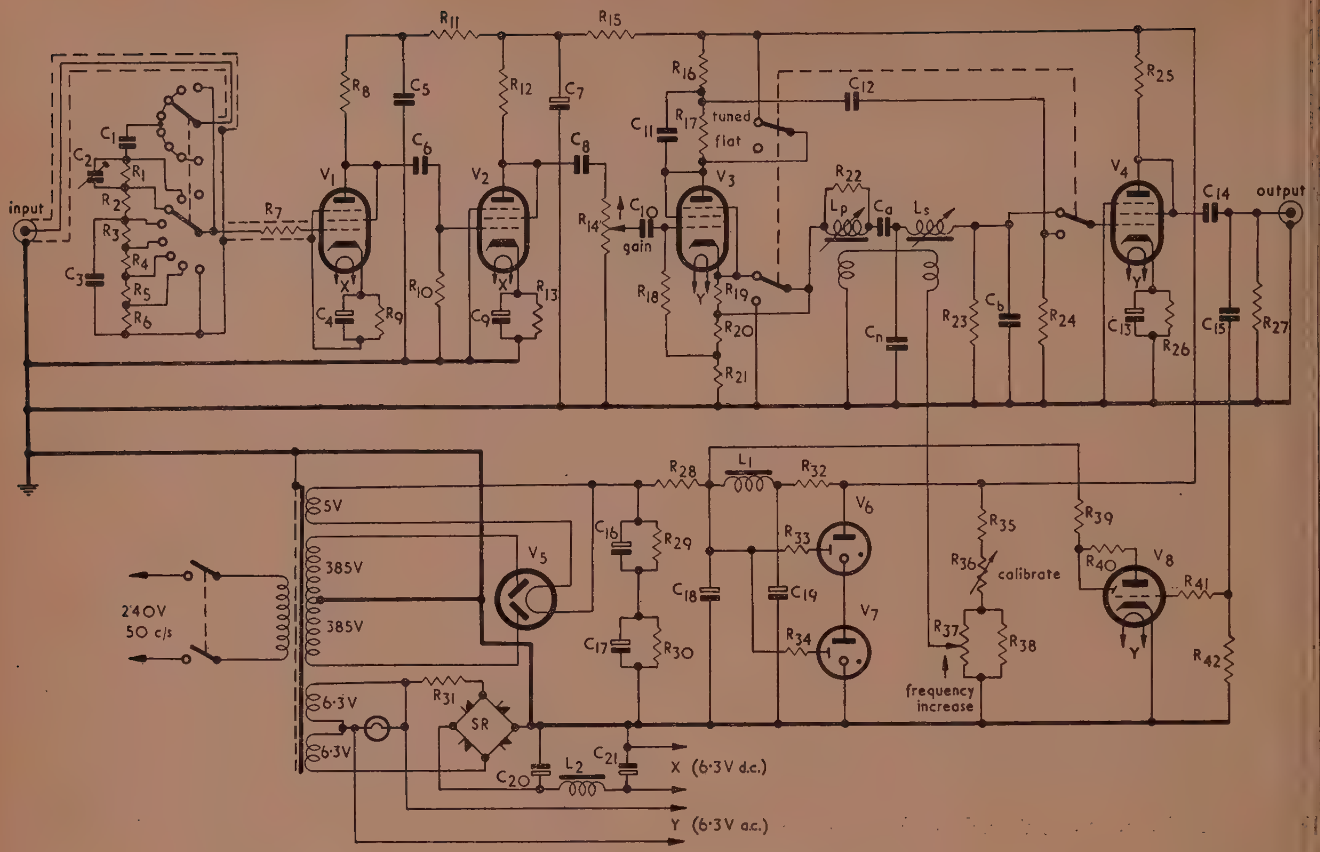

R11
R15
R8
C5
R12
C7
R16
C12
R25
C1
C2
R1
R2
R3
C3
R4
R5
R6
input
R7
V1
C6
V2
C8
C11
R17
tuned
flat
V3
R22
V4
C14
output
Lp
Ca
Ls
R14
C10
gain
X
Y
R10
R13
C4
R9
C9
R18
R19
R20
R21
R23
Cb
R24
Cn
C13
R26
C15
R27
L1
R28
R32
5V
385V
385V
240V
50 c/s
V5
C16
R29
R33
V6
R35
R39
R36
calibrate
R40
V8
R41
C18
C19
V7
R37
R38
R42
C17
R30
R34
frequency increase
6·3V
6·3V
R31
SR
C20
L2
C21
X (6·3V d.c.)
Y (6·3V a.c.)

Fig. 1. Circuit diagram of detector-amplifier

$R_1 = 1\ \text{M}\Omega$
$R_2 = 100\ \text{k}\Omega$
$R_3 = 10\ \text{k}\Omega$
$R_4 = 1\ \text{k}\Omega$
$R_5 = 100\ \Omega$
$R_6 = 11{\cdot}1\ \Omega$
$R_7 = 10\ \text{k}\Omega$
$R_8 = 250\ \text{k}\Omega$
$R_9 = 5\ \text{k}\Omega$
$R_{10} = 1\ \text{M}\Omega$
$R_{11} = 50\ \text{k}\Omega$
$R_{12} = 250\ \text{k}\Omega$
$R_{13} = 5\ \text{k}\Omega$

$R_{14} = 500\ \text{k}\Omega$
$R_{15} = 25\ \text{k}\Omega$
$R_{16} = 7\ \text{k}\Omega$
$R_{17} = 20\ \text{k}\Omega$
$R_{18} = 2\ \text{M}\Omega$
$R_{19}, R_{20} = 600\ \Omega$
$R_{21} = 25\ \text{k}\Omega$
$R_{22}, R_{23} =$ see text
$R_{24} = 1\ \text{M}\Omega$
$R_{25} = 100\ \text{k}\Omega$
$R_{26} = 2{\cdot}5\ \text{k}\Omega$
$R_{27} = 1\ \text{M}\Omega$
$R_{28} = 15\ \text{k}\Omega$

$R_{29}, R_{30} = 250\ \text{k}\Omega$
$R_{31} \simeq 6\ \Omega$
$R_{32} = 10\ \text{k}\Omega$
$R_{33}, R_{34} = 250\ \text{k}\Omega$
$R_{35} = 50\ \text{k}\Omega$
$R_{36} = 10\ \text{k}\Omega$
$R_{37} = 5\ \text{k}\Omega$
$R_{38} = 2\ \text{k}\Omega$
$R_{39} = 50\ \text{k}\Omega$
$R_{40}, R_{41} = 1\ \text{M}\Omega$
$R_{42} = 5\ \text{M}\Omega$

V_1–V_4 = EF91

V_5 = 5Y3–GT
V_6, V_7 = QS95/10
V_8 = 6U5

$C_1 = 0{\cdot}05\ \mu\text{F}$
$C_2, C_3 =$ see text
$C_4 = 100\ \mu\text{F}$
$C_5 = 4\ \mu\text{F}$
$C_6 = 0{\cdot}1\ \mu\text{F}$
$C_7 = 14\ \mu\text{F}$
$C_8 = 0{\cdot}1\ \mu\text{F}$
$C_9 = 100\ \mu\text{F}$
$C_{10} = 0{\cdot}1\ \mu\text{F}$

$C_{11} = 0{\cdot}005\ \mu\text{F}$
$C_{12} = 0{\cdot}1\ \mu\text{F}$
$C_{13} = 100\ \mu\text{F}$
$C_{14} = 0{\cdot}1\ \mu\text{F}$
$C_{15} = 0{\cdot}005\ \mu\text{F}$
C_{16}–$C_{19} = 14\ \mu\text{F}$
$C_{20}, C_{21} = 1000\ \mu\text{F}$
$C_a, C_b, C_n =$ see text

$L_1 = 30\ \text{H}$
$L_2 = 0{\cdot}5\ \text{H}$
$L_s, L_p =$ see text
SR = selenium rectifier

response is obtained. If Q_p and Q_s are constant over the tuning range, the same ratio of actual coupling to critical coupling is maintained, and the voltage gain $|V_0/V_i|$ is independent of frequency. In the actual filter, additional damping has been provided by means of resistors R_{22}, R_{23} (Fig. 1) in parallel with an inductor or a capacitor in order to equalize the Q-factors for each circuit at both extremes of the tuning range. In the final circuit $Q_p = 10$ and $Q_s = 14$ at these extremes, giving a filter gain of about $5\frac{1}{2}$ times. In the centre of the tuning range the Q-factors rise a little giving the filter a slightly greater gain.

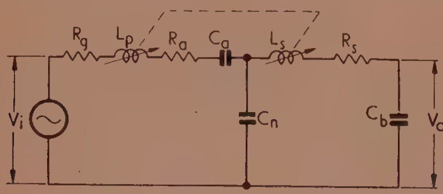

Rg
Lp
Ra
Ca
Ls
Rs
Vi
Cn
Cb
Vo

Fig. 2. Capacitively-coupled filter

The filter is driven by a cathode follower with an effective output resistance of approximately $250\ \Omega$. Fixed mica-dielectric capacitors of approximately $0{\cdot}2\ \mu\text{F}$ are used for C_a and C_b and a paper-dielectric capacitor 10 times this value for C_n. The inductors L_p and L_s are identical saturable reactors each consisting of two series-connected a.c. coils of 4000 turns wound on the outer limbs of a $\frac{7}{16}$ in. stack of inter-leaved $0{\cdot}005$ in. Mumetal laminations (type 36T by Telegraph Construction and Maintenance Co.). A d.c. control winding of 3000 turns is on the centre limb. The outer coils are connected so that the mutual inductance between the control winding and the a.c. coils is zero. The control windings of the two reactors are connected in series and supplied with direct current from a variable voltage divider connected to the regulated h.t. supply. To ensure close matching of the two cores, the laminations, when taken from the stock supply, were assigned alternately to one and the other core. A small residual difference in the control characteristics of the two reactors was corrected by shunting the d.c. control winding of one of them. In Fig. 3 the inductance ratio L_0/L is shown as a function of the d.c. control current. L is the inductance with d.c. excitation and L_0 the inductance without excitation. Since the tuning frequency is proportional to $(1/L)^{\frac{1}{2}}$, and L_0/L in Fig. 3 is lotted on a logarithmic scale, the frequency characteristic s of similar shape but of half the slope. The resistors in he d.c. supply circuit have been chosen for the best law of requency with dial rotation.

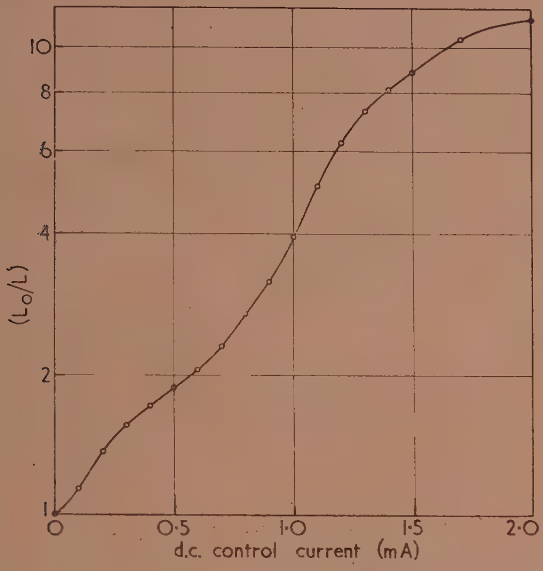


Fig. 3. Inductance variation of saturable reactors

The location of the filter in the circuit with respect to ignal levels is a matter of some importance. When the uning control is operated small transient voltages appear, lue to irregular changes in the magnetization process. The mplification after the filter stage must not be so great as to ring these transient effects into prominence. On the other hand, at excessively high signal levels, non-linearity in the nductors and cathode follower becomes significant. Forunately there is a range of signal levels over which neither of hese effects is important and the filter is located so that the ignal level is within this range. Under these conditions the uning is smooth, stable and free from hysteresis effects, and he inductors, which are unscreened, are not susceptible to nains pickup from stray magnetic fields. The use of Mu-netal screens would, however, allow greater flexibility of ayout, since the principal source of stray field is the power ransformer on the same chassis.

Amplifying stages. Triode-connected type EF91 valves re used in all stages. This tube, in the triode connexion, vas found to be the most satisfactory with regard to nicrophony of several types that were tested. In addition it ossesses an amplification factor exceeding 50, and a stage ain approaching this figure can easily be obtained in a low-requency amplifier. Two stages (V_1, V_2) provide sufficient mplification to feed the cathode follower, V_3, driving the lter. The heaters of the first two tubes are operated on d.c. upplied by a selenium rectifier and filter. This reduces the quivalent mains hum, referred to the input grid to less than μV for an input impedance of 1 MΩ. Very great care vas taken with the wiring of the low-level stages to avoid ops into which voltages could be induced, and to exclude arth currents from the signal circuits. The amplifier may e operated either tuned or "flat," and in order to keep the ain unchanged in switching to the "flat" response, the athode follower is converted to a voltage amplifier with a ain equal to that of the filter stage. In the "flat" position the high-frequency response is improved by means of a simple compensating network in the anode circuit.

A final amplifying triode stage, V_4, raises the signal level to a value sufficient for application to the electron-ray tube indicator, V_8, or to a cathode-ray oscilloscope. The amplifier has been designed to give a maximum undistorted output of about 20 V which is ample for the usual oscilloscope with self-contained amplifier.

Balance indicator. Although the amplifier is intended primarily for use in conjunction with a cathode-ray oscilloscope, an electron-ray tube indicator ("magic eye") is incorporated to make it a self-contained amplifier-detector. The tube used, a type 6U5, is of the remote cut-off type and consequently has its greatest sensitivity at low voltages, a useful feature in a bridge detector.

Input attenuator. The switched resistive potential divider at the input provides attenuations from 1 to 10^5 in steps of ×10. In one position of the attenuator control, the input is applied directly to the grid with no grid-leak or isolating capacitor. When the amplifier is used in this way a d.c. grid to cathode return path must be provided in the connected circuit. There are many applications in which this "direct to grid" connexion is of great value. Examples are: (i) measurements in high impedance circuits where the greatest possible sensitivity is required; (ii) Q-measurements by resonant-circuit techniques where absence of damping by the measuring circuit is a primary consideration; (iii) applications in which a tuned input transformer is used and where the damping of grid leak is inadmissible.

The capacitors C_2 and C_3 are used to improve the attenuator accuracy at high audio frequencies—when the amplifier is on "flat" response—by compensating for some of the effects of stray and valve input capacitances.

Power supplies. The mains-operated power unit provides a.c. and d.c. heater supplies, and a regulated 190 V h.t. supply. It is mounted on the same chassis as the rest of the amplifier but as far away as possible from the input stages and tuning inductors. Stray fields at these critical points are kept small by judicious placing of the power transformer and by the use of an aluminium chassis and case.

PERFORMANCE

The frequency response of the amplifier is shown in Fig. 4 for three tuning frequencies. The third harmonics, usually

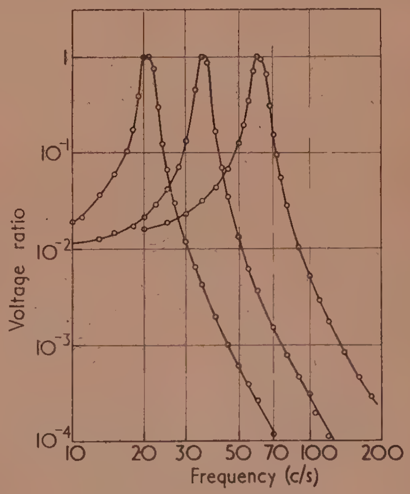


Fig. 4. Selectivity curves of tuned amplifier

the most troublesome in power-frequency measurements, are attenuated by a factor of approximately 4000 times. When in the "flat" position the response is constant within 3 dB from 10 c/s to 10 kc/s and in both positions the maximum gain is approximately half a million. When tuned, the minimum signal that can be detected in a source of 1 MΩ resistance is 1 μV using an electron-ray indicator and $\frac{1}{4}$ μV when using a cathode-ray oscilloscope with a sinusoidal time base in phase with the signal output.

Simple intermodulation tests showed that there was no significant production of fundamental voltages by intermodulation between consecutive harmonics. For example, in one test at full amplifier gain an input of 500 μV both of second and of third harmonic caused intermodulation equivalent to 1 μV of fundamental voltage. In normal power-frequency bridge applications only odd harmonics are present in appreciable magnitudes and fundamental voltages can be produced only by higher order processes, making the problem less acute.

INPUT TRANSFORMERS

When the detector is used for measurements in low-impedance circuits a considerable increase in sensitivity can be obtained by the use of an input transformer, which may be tuned if the highest sensitivity is required. With transformer cores of thin nickel-iron alloy such as Mumetal, both high permeability and low eddy-current loss are possible, and since hysteresis losses are of no significance at the very low inductions that occur in the transformer, a useful Q-factor can be achieved even at quite low frequencies. For example, with a fully interleaved core of 0·005 in. Mumetal, 0·25 in.^{2} in cross-sectional area, a permeability of 10 000 and a Q of 30 for the high impedance secondary are readily obtained.

A typical transformer used with the amplifier described above has a secondary of 9000 turns and primaries of 10, 30 and 90 turns giving step-up ratios of 900, 300 and 100 respectively. The input impedance at 50 c/s on, for example, the 900/1 ratio, is 1 Ω, but when the secondary is tuned the input impedance increases to 25 Ω. Another turned transformer for use in measurements in very low impedance circuits has a step-up ratio of 10 000—it has a single turn primary—and an input impedance of approximately 0·1 Ω. Its dimensions are quite small, the cylindrical Mumetal screen enclosing it being between $\frac{3}{4}$ and 1 in. in outside diameter.

Although tuning of the transformer may sometimes be turned to advantage in improving the filtering action of a detector-amplifier this is not usually its primary purpose. Its greatest value lies in the higher turns ratio that may be used for the same primary impedance by reducing the primary turns. It can be shown that the possible increase in ratio is equal to $\sqrt{Q}$, approximately.

Very complete magnetic shielding and special mounting to exclude vibration and shock are essential if the transformers are to operate at signal levels comparable with the noise level of the amplifier. However, when these precautions are taken, the contribution to noise power by the transformer is negligible. In point of fact, the signal-to-noise ratio is improved owing to the narrower band-width resulting from the tuned transformer.

REFERENCES

(1) Sturtevant, J. M. *Rev. Sci. Instrum.*, **18**, p. 124 (1947).

(2) Scroggie, M. G. *Wireless Wld*, **57**, p. 175 (1951).

(3) Rayner, G. H. *J. Sci. Instrum.*, **30**, p. 17 (1953).

(4) Looms, J. S. T. *J. Sci. Instrum.*, **30**, p. 290 (1953).

(5) Aiken, C. B. *Proc. Inst. Radio Engrs*, **25**, p. 230, and errata, p. 672 (1937).

A rotational viscometer for surface films

By S. C. Ellis, B.Sc., Ph.D., A.R.I.C., A. F. Lanham, B.Sc., A.R.I.C., and K. G. A. Pankhurst, B.Sc., Ph.D., F.R.I.C.,
The British Leather Manufacturers' Research Association, Egham, Surrey

[*Paper first received* 22 *April, and in final form* 11 *August*, 1954]

The surface viscosity of monomolecular surface films (monolayers) spread on water has been measured with an instrument analogous to the coaxial cylinder (Couette) viscometer. A ring of platinum wire, coated with paraffin wax, is floated on the film-covered surface and rotated by a synchronous motor, transmission being through a torsion wire. The viscous drag imposed by the film on the rotating ring is calculated from the angular displacement between the ends of the torsion wire. Specimen results for serum albumen, showing its non-Newtonian behaviour, are given.

Two main methods have been used to measure the viscosity of monomolecular surface films (monolayers) spread on water. Both have been derived from conventional three-dimensional techniques, i.e. (i) the "surface slit" viscometer in which the monolayer is allowed to flow under pressure through a narrow channel (compare the Ostwald viscometer), by means of which the surface viscosity can be calculated using a method analogous to the Poiseuille treatment$^{(1-3)}$; (ii) various oscillation techniques in which the damping of a needle or disk floating in the surface is measured.$^{(4-8)}$ Certain objections can be raised against both of these methods. Firstly, since the surface viscosity of a monolayer may vary considerably with surface pressure (i.e. according to its state of aggregation), methods which rely on a pressure gradient, such as the surface slit or canal, are liable to produce changes of state in the film in the course of the determination. The slit method does, however, provide the most sensitive means for measuring low surface viscosities (i.e. below about 10^{-2} surface poise). The oscillation of a needle or vane in the surface is open to the same objection since the portion of the film in front of the advancing edge undergoes temporary compression while that behind the receding edge becomes expanded. This objection is overcome by a disk or ring, but this still suffers from a second disadvantage in that the rate of shear cannot be kept constant and is virtually indeterminate. A rotational viscometer, analogous to the Couette nstrument for bulk systems, overcomes both of these difficulties. It allows the surface viscosity to be measured at onstant pressure. Moreover, by studying the relationship etween apparent surface viscosity and angular velocity of otation, it enables non-Newtonian behaviour to be detected. Recently Chaminade, Dervichian and Joly(9) have contructed such an instrument in which the viscous drag imposed y a monolayer on a rotating ring is measured by a hairpring device, transmission between ring and measuring pparatus being through a trifilar suspension of threads. In he instrument described below, a simple torsion wire replaces he hair spring and the deformable trifilar transmission is eplaced by a rigid connexion between ring and torsion wire. This has led to greater sensitivity, range and accuracy.

EXPERIMENTAL DETAILS

All experiments were carried out using a trough of either erspex or polyvinyl chloride, approximately 80 × 20 cm nd 1·5 cm deep, partly filled with water. The surface on vhich the film is spread is bounded by a floating framework f mica sheet, slightly smaller than the internal dimensions of he trough, cut to the desired shape (Fig. 1) and coated with araffin wax (m.p. 60°) to give a high contact angle against vater. This framework is located in position by four rigidlylamped glass guide rods engaging in holes H at each end. A waxed mica barrier B, held down by small lead weights L t each end, is used to adjust the film area. The surface ressure is measured by Guastalla's method,(10) in which a mall waxed mica float F is used to separate the film from a mall clean water surface C, the film-tight seal being completed by silk or nylon threads T coated with Vaseline. The loat F is attached by a two-pronged fork assembly, which arries an optical lever mirror, to a vertical torsion wire W_1. This is so arranged that the float pivots about the line of the orsion wire under the influence of a surface pressure ifference, any appreciable lateral movement being prevented y the mass of the fork assembly (about 35 g). The surface nanometer is used as a null instrument, the surface pressure Π) being related to the angular twist on the torsion head (α) s follows:

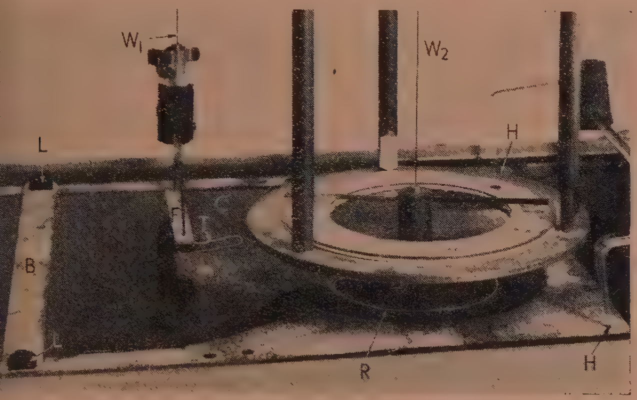


Fig. 1. Rotational surface viscometer

$$\Pi = 2c\alpha/ab \qquad (1)$$

vhere c = torsional constant of the wire
a = length of the float
b = distance between the torsion wire and the framework immediately opposite the other end of the float.

Using a phosphor-bronze wire 25 cm long and 0·2 mm diameter, with a float 6·5 cm long and a gap of 1 cm (i.e. $a = 6{\cdot}5$, $b = 7{\cdot}5$) a sensitivity of 0·07 dyn cm per degree was obtained.

The surface viscosity is measured in the circular compartment adjacent to the clean water surface. A ring of platinum wire R coated with paraffin wax is floated in the centre of this compartment on a clean water surface before the monolayer is applied. The ring is provided with three short lugs disposed symmetrically about the circumference and normal to the plane of the ring. It is rotated through a gearbox driven by a synchronous motor, the transmission being through a torsion wire W_2 attached at one end to the drive and at the other to a small brass bob fitted with three radial arms drilled to engage the lugs of the floating ring. It is essential that the ring, when connected to the drive, is concentric with the circular compartment of the framework.

The most satisfactory method of cleaning irregularly-shaped surfaces, such as those in the present instrument, is by means of a jet of compressed air which is used to concentrate the spread impurities to one corner of the framework. These are then sucked off by a small glass jet connected to a water pump. The boundary of the contaminating dirt is readily seen by lightly dusting the surface with clean talc.(10) The monolayer is spread on to the large cleaned water surface and is allowed to flow into the annular space between the ring and the edge of the circular compartment. The surface pressure is adjusted to any desired value by moving the barrier B and the ring set in rotation. The film imposes a viscous drag which is transmitted to the lower end of the torsion wire causing a couple to be set up. The angular displacement which this causes between the two ends of the wire is measured by a pointer attached to the brass bob at the lower end, which reads on a circular rotating scale attached direct to the driving shaft. The whole apparatus is screened from draughts by enclosing it in a celluloid box, which is not shown in Fig. 1.

It will be appreciated that the viscous drag on the ring arises not only from the molecules of the film, but also from the water molecules immediately under the film. In calculating the surface viscosity, therefore, it is necessary to measure the drag exerted by the water in the absence of the film, and to use the difference between this value and that for the film-covered surface for calculation of the surface viscosity. This procedure would seem to be justified for a Newtonian film where the distribution of velocities across the annulus is the same for both clean and film-covered surfaces. The correction, however, must be in error when non-Newtonian behaviour in the film results in a different distribution of velocities in the water from that obtaining in the absence of the monolayer. If the torque due to the water molecules is small compared to that due to the film, then an error in the former will result only in a small error in the corrected torque assigned to the film proper. The table shows the ratio of torque due to the water molecules and that due to the film, for an angular velocity of 0·18 rad/s, at three apparent viscosities (corresponding to observations

Apparent viscosity *(surface poise)*	$\dfrac{\textit{Torque due to water}}{\textit{Torque due to film + water}} \times 100$ (%)
0·02	31
0·13	6
0·31	3

on serum albumen, Fig. 4). The values suggest that for non-Newtonian films of apparent viscosity greater than about 0·1 surface poise, the error is small, and since non-Newtonian behaviour is only usually found in more viscous monolayers, it is concluded that this procedure is satisfactory.

The calculation of surface viscosity (η) from the corrected angular displacement is made by a precisely analogous method to that used in the three-dimensional Couette instrument.(11) Let Ω be the angular velocity of the inner ring of radius R_1 (Fig. 2), and τ the torque applied to it.

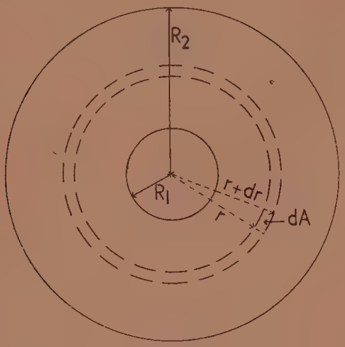


Fig. 2

Then for Newtonian behaviour, considering a small area element dA at radius r, and writing the rate of shear at this point as D, the energy dissipated per second (e) is given by:

$$e = \eta D^2 dA \tag{2}$$

$$= (s^2/\eta) dA \tag{3}$$

If s is the linear shearing stress at radius r, then:

$$s = \tau/2\pi r^2 \tag{4}$$

therefore

$$e = (\tau^2/4\pi^2 r^4 \eta).2\pi r.dr \tag{5}$$

Hence the total energy dissipated over the annulus per second (E) is:

$$E = \frac{\tau^2}{2\pi\eta}\left[-\frac{1}{2r^2}\right]_{R_1}^{R_2}$$

$$= \frac{\tau^2}{4\pi\eta}\left[\frac{1}{R_1^2} - \frac{1}{R_2^2}\right]$$

$$= \tau\Omega \tag{6}$$

which leads to the following expression for the surface viscosity:

$$\eta = \frac{\tau}{4\pi\Omega}\left[\frac{1}{R_1^2} - \frac{1}{R_2^2}\right] \tag{7}$$

in which $\tau = c\Delta$, where c is the torsional constant of the wire and Δ is the corrected angular displacement of the wire due to the film, i.e. $\Delta_{\text{film}} - \Delta_{\text{water}}$. Equation (7) is, of course, only true for a Newtonian film.

The mean rate of shear ($\bar{D}$) can be obtained from the total energy dissipated over the whole annulus, thus:

$$E = \pi(R_2^2 - R_1^2)\eta\bar{D}^2 \tag{8}$$

By substituting the expression for E given in equation (6), the mean rate of shear becomes:

$$\bar{D} = 2R_1R_2\Omega/(R_2^2 - R_1^2) \tag{9}$$

Equation (9) can be simplified if $R_2 \simeq R_1$, and the following expression is obtained:(12)

$$\bar{D} = R_1\Omega/(R_2 - R_1) \tag{10}$$

Whereas with the conventional Couette viscometer for bulk systems, R_2 and R_1 can be made nearly equal, this cannot be achieved with the two-dimensional pattern owing to the curvature of the surface, due to the high contact angle, making centring almost impossible. In practice, it is found that an annulus of about 2 cm width is essential for convenient manipulation, and in the present instrument $R_1 = 3$ cm and $R_2 = 5$ cm. Equation (10) cannot therefore be applied with accuracy for, assuming an angular velocity of 1 rad/s, this gives $\bar{D} = 1{\cdot}50\ \text{s}^{-1}$, whereas the correct value obtained from equation (9) gives $\bar{D} = 1{\cdot}87\ \text{s}^{-1}$.

A simple test for Newtonian behaviour can, however, be obtained by plotting apparent viscosity (η), derived from equation (7), against angular velocity (Ω), when any anomalous flow results in a variation of η with Ω. It is desirable that the dimensions of the annulus should also be given so that absolute calculations can be made if required.

CONSTRUCTIONAL DETAILS

Fig. 3 shows in detail the construction of the viscometer. A ring of platinum wire (25 s.w.g.), 6 cm in diameter has three lugs approximately 5 mm long welded equidistantly around its circumference. When not in use this was kept on a conical perspex former to preserve its shape. The radial arms connecting ring and torsion wire were cut from a disk of 16 gauge Duralumin after bolting it to the cylindrical brass bob (weight about 25 g), which also carried a Duralumin pointer, care being taken to maintain symmetry.

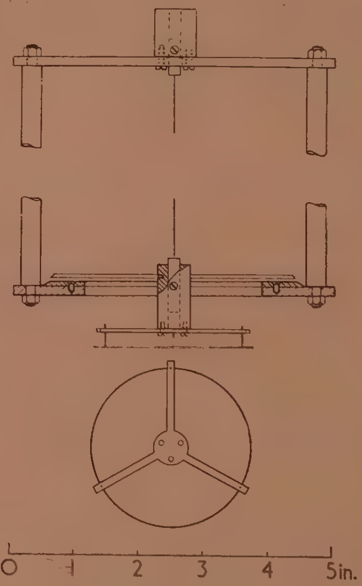


Fig. 3. Construction of surface viscometer

Each arm was drilled to take the lugs of the ring, the fit being slightly loose to permit the vertical movement of the ring as the level of the liquid in the trough fell during cleaning of the surface.

To facilitate interchange of torsion wires they were soldered into centrally-drilled brass cylinders, $\frac{3}{8}$ in. in diameter at each end, which were push fits into centrally-drilled holes in the lower brass bob and upper driving shaft. Where very fine wires were used, great difficulty was experienced in drilling a sufficiently fine hole in the brass cylinders to ensure good centring. This was overcome by bushing a larger hole with Accles and Pollock precision tubing of appropriate internal diameter.

Using phosphor-bronze wires of 42 and 47 s.w.g. and 35 cm in length, angular displacements up to 3000° were obtained, which correspond to about 0·3 and 5·0 surface poise respectively for $\Omega = 0{\cdot}6$ rad/s. No permanent set in the wires was observed. The accuracy with which a deflexion can be read on the rotating scale depends largely on the speed of rotation, and varies from about ± 1 to $\pm 5°$ as Ω is increased from 0·2 to 2·5 rad/s.

The scale was mounted on a brass annulus accurately centred on three shouldered supports. Variations of the speed of rotation were obtained using a two-stage multi-pulley gearbox and spring cord belting. Driving speeds from 1·8 to 24 rev/min were obtained from a synchronous motor of 25 rev/min output.

SPECIMEN RESULTS

Fig. 4 gives surface viscosities of serum albumen films spread in the usual way,$^{(13)}$ from 0·4% amyl alcohol in water, on hydrochloric acid at pH 3·2. This monolayer shows three distinct physical states: liquid, plastic and gel, according to pressure. At 3 dyn/cm it is liquid and almost Newtonian. When compressed to 6 dyn/cm, it becomes plastic and anomalous flow is seen, the apparent viscosity decreasing at the higher angular velocities. On further compression to 10 dyn/cm, a two-dimensional gel is formed and anomalous viscosity is even more pronounced. Throughout the range of pressures and rates of rotation studied, the monolayers are reversible. The circles represent results obtained on an ascending velocity gradient, and the crosses indicate values when the angular velocity was suddenly reduced from the highest value to the lowest. In one experiment, the film having been compressed to 10 dyn/cm and its viscosity measured at a number of velocities was re-expanded to 6 dyn/cm and its viscosity was found to coincide with that originally obtained at that pressure (triangles in Fig. 4).

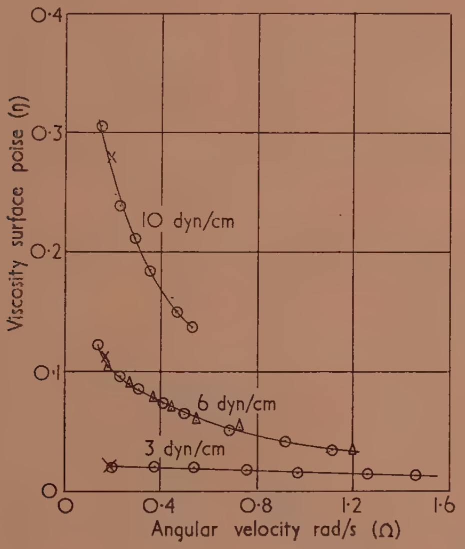


Fig. 4. Surface viscosity of serum albumen monolayers spread on hydrochloric acid (pH 3·2), 20°

ACKNOWLEDGEMENTS

We are indebted to the Director and Council of the British Leather Manufacturers' Research Association for permission to publish this paper, also to Drs. D. G. Dervichian and M. Joly who first introduced us to this method of measuring surface viscosity and provided one of us (S.C.E.) with facilities for studying their original instrument at the Institut Pasteur in Paris.

REFERENCES

(1) Bresler, S. E., Talmud, D. L., and Talmud, B. A. *Phys. Z. Sowjet*, **4**, p. 864 (1933).

(2) Joly, M. *J. Phys. Radium*, **8**, p. 471 (1937).

(3) Myers, R. J., and Harkins, W. D. *J. Chem. Phys.*, **5**, p. 601 (1937).

(4) Plateau, J. *Statique expérimentale et théorique des liquides soumis aux seules forces moléculaires*, Vol. II, p. 47 (Paris: Gautier-Villars, 1873).

(5) Rayleigh, Lord. *Proc. Roy. Soc. A*, **48**, p. 127 (1890).

(6) Langmuir, I. *Science*, **84**, p. 378 (1936).

(7) Harkins, W. D., and Myers, R. J. *Nature* [*London*], **140**, p. 465 (1937).

(8) Joly, M. *Kolloid. Z.*, **89**, p. 26 (1939).

(9) Chaminade, R., Dervichian, D. G., and Joly, M. *J. Chim. Phys.*, **47**, p. 883 (1950).

(10) Guastalla, J. *C. R. Acad. Sci.* [*Paris*], **189**, p. 241 (1929).

(11) Couette, J. *Ann. Chim. Phys.*, **21**, p. 433 (1890).

(12) Ward, A. G., and Freeman, P. R. *J. Sci. Instrum.*, **25**, p. 387 (1948).

(13) Adam, N. K. *The Physics and Chemistry of Surfaces*, 3rd Ed., pp. 27–44 (Oxford University Press, 1941).

Laboratory and workshop notes

Liquid developers for xerography

By K. A. Metcalfe, B.Met.E., Defence Standards Laboratories, Woodville, South Australia

[*Note received* 30 *August*, 1954]

In xerography,(1) or non-chemical photography, an electrostatic image is formed which is developed by application of charged powder. As the name implies, xerography (Greek "xeros" meaning dry) has evolved essentially as a dry process, and the absence of liquids has been regarded as one of its main features. The two accepted methods of developing latent electrostatic images are referred to as the "cascade" and "powder-cloud" methods;(2) the former is more appropriate for high contrast sharp line images, and the latter produces excellent half-tone images with good latitude.

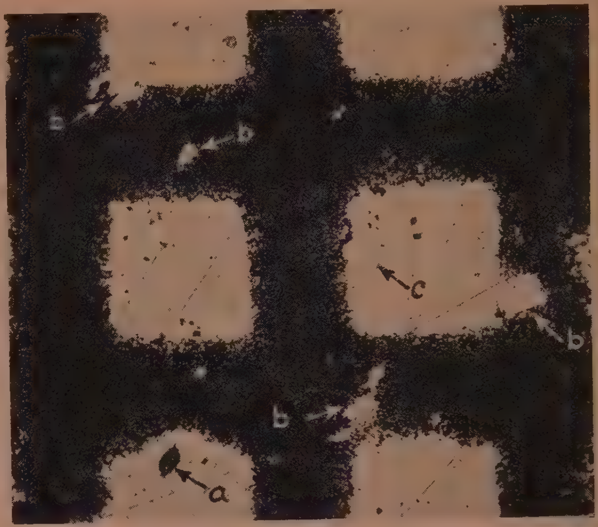
In both methods, fine powder particles up to 20 μ are used as the developing agent. In cascade development, the active powder is mixed with an inert carrier powder (200 to 300 μ); in powder-cloud development, the active powder particles are dispersed in air. The author's experience with the two methods of development confirms the conclusions of Oliphant(3) that greater control is obtainable with the powder-cloud method, in which a precipitator grid is employed to prevent particles of unwanted charge sign reaching the xerographic plate.

In course of work with selenium-coated plates made at the Defence Standards Laboratories, it has been found that development based on liquid dispersion media offers better control than either of the dry processes; furthermore, considerably shorter development times are possible. Liquids investigated include petrol, kerosene, turpentine, benzol and carbon tetrachloride; they were selected because of their high resistivity, a property which is essential to avoid discharge of the latent electrostatic image. Many powders (including certain talcum powders, magnesium oxide, carbon black and a number of pigments) disperse freely in these liquids and in so doing acquire a charge, the sign of which is characteristic of the powder. As examples, particles of "monolite yellow" pigment acquire positive charges and are attracted to negatively charged latent images; talcum powder particles acquire negative charges. The process is clearly an example of the phenomenon known as electrophoresis or cataphoresis.(4)

Xerographic plates may be developed in these liquid developers either in tanks or in dishes; development time ranges from one to ten seconds according to the particular developer used. The images are ready for examination immediately after development; they are not impaired by exposure to light in either the wet or the dry condition. The overall density of the powder deposit for a given plate charge and exposure is dependent on the particle concentration in the liquid, the distance between the plate and the side of the tank or other electrode, and the time of development. The "grain" of the image is a function of the size of the powder particles, of the uniformity or otherwise of their dispersion in the liquid, and of the extent to which the developer is agitated.

Although contrast and definition of the image are governed primarily by the charge distribution on the xerographic plate itself, some control is possible in development. Under-development gives a contrasty but thin image, lacking in definition. Over-development, by producing excessively thick deposits, reduces contrast and impairs definition. To obtain optimum contrast, it is necessary to agitate the plate or the developer or both.

The photograph shows (at a linear magnification of ×50) a xerograph of a forty-mesh I.M.M. (Institute of Mining and Metallurgy) screen developed with "monolite yellow" dispersed in petrol. The effects of (*a*) porosity in the coating of the plate, (*b*) conductive spots (due to the presence of hexagonal selenium),(3, 5) and (*c*) plate scratches will be noted.



Enlargement of xeroradiographic image of forty-mesh I.M.M. screen (×50)

Target-to-film distance, 5 ft; object-to-film distance, 1¼ in.; target size, 2 × 2 mm approximately.

The chief advantages of liquid development are greater simplicity and speed of operation coupled with improved control and versatility. Vibration of the powder to impart charges to the particles is unnecessary, as the particles automatically acquire a charge when dispersed in the liquid. Furthermore, for each particular powder, all the charges are of the same sign and there is accordingly no need to employ a precipitator grid to reject particles of unwanted sign. It is possible to produce images of mixed colours by the blending of particles of different colour but of similar charge sign; it is also possible to develop simultaneously both the image and the background by using two powders which take on charges of opposite sign when dispersed in the liquid.

Concentration and size of particles in the liquids may be varied by levigation of the powder in the developer liquid itself. Loss of particles other than by deposition on the plate is negligible. Although drying of developed plates is rapid with most of the liquids used, drying time is relatively unimportant as wet images are just as satisfactory as dry images for visual inspection and offer a method of image transfer by adsorption by paper, in addition to the usual methods of electrical or adhesive transfer.

A fuller account of this work will be published elsewhere.

This paper is published by permission of the Chief Scientist, Department of Supply, Australia.

REFERENCES

(1) Schaffert, A. M., and Oughton, C. D. *J. Opt. Soc Amer.*, **38**, p. 991 (1948).

) McMaster, R. C. *Non-destr. Test.*, **10**, p. 8 (1951).
) Oliphant, W. D. *Discovery*, **14**, p. 175 (1953).
) Creighton, J. H. *Principles and applications of electrochemistry*, 4th ed. (New York: John Wiley and Sons Inc., 1947).
) Keck, P. H. *J. Opt. Soc. Amer.*, **42**, p. 221 (1952).

A compact high voltage static electrification eliminator*

By D. T. R. Dighton, M.Sc., A.R.C.S., A.Inst.P., Research Laboratories, Kodak Ltd., Harrow, Middlesex

[*Note received* 22 *July*, 1954]

tatic electricity eliminators of the needle type, in which a igh voltage (5–15 kV, a.c. or d.c.) is applied to a series of harp points, are well known and are widely used in the paper nd textile industries. The provision of adequate safety neasures for these devices presents a difficult problem, since is usually necessary for the needles to be exposed. Suitable imiting resistances are normally incorporated in the high-oltage supply lead and, in some cases, in series with each ndividual needle. In spite of these precautions, sparks and light shocks can be drawn from the points, and while there s no danger to human life, the impression is given that the pparatus is unsafe. In some cases also the sparks which an be drawn from the needles to an earthed object constitute serious fire risk and make the installation of this type of liminator unwise. The bulkiness of the apparatus often revents its being placed in the most advantageous position.

These considerations have led to the development of a tatic eliminator which has no exposed high-voltage electrode. central 16 s.w.g. steel wire connected to a 6 kV, 50 c/s upply is sheathed by an insulating sleeve with a wall thickess of about 1 mm. Round the outside of this sleeve is vound an earthed spiral of 28 s.w.g. wire having a pitch of bout 0·5 cm. This arrangement gives a high-voltage radient at the surface of the earthed spiral resulting in the eneration of quantities of ions of both signs. The overall liameter of the eliminator is about 3·5 mm, and it can thus e placed where the use of a conventional needle eliminator s not possible. Furthermore, it is flexible and can be shaped o suit a particular location.

The choice of the material for the insulating sleeve is not n easy one, since it must continuously withstand a high-oltage gradient and be unaffected by the ozone generated luring operation. Further, the performance of the eliminator s improved by keeping the volume resistivity low, thereby iding the generation of ions. This property and a high lielectric strength are not commonly found together. A onsiderable number of insulating materials were tested, ncluding polyvinyl chloride, polythene, neoprene and glass, ut all broke down after a few hundred hours' operation. The only material which has proved satisfactory is a sleeving f silicone rubber (Symel sleeving by H. D. Symons and Co.) aving a wall thickness of 0·75 mm. This has been found to perate satisfactorily for several thousand hours without any ign of breakdown.

The "earthed spiral" eliminator is not as effective as a eedle eliminator supplied with the same voltage. For xample, tests carried out in conjunction with the Shirley nstitute showed that the currents drawn from the eliminator y charged fibres are inadequate for effective discharging. It as, however, been found to give useful discharging of sheets of insulating material moving at speeds of 1–2 ft/s. As an indication of the effectiveness of the unit, it is found that currents of 1 μA can be drawn from a 12 in. eliminator to a plate held at 5 kV at a distance of 2 in. from the eliminator.

A device for preparing gas mixtures

By N. R. Hansen, B.Sc., New South Wales University of Technology, Australia

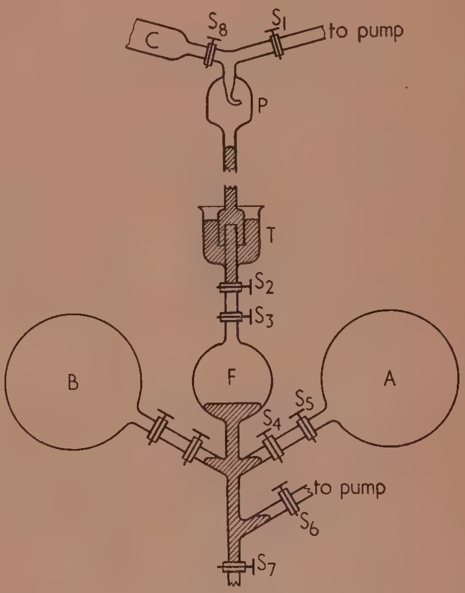
[*Note first received* 14 *July, and in final form* 29 *September*, 1954]

In filling proportional counters with mixed gases the following apparatus was devised to overcome objections that arose in the use of better-known gas-handling devices. The chief objections included:

- (i) the difficulty of measuring the partial pressure of each component;
- (ii) the danger of polluting one gas source with another gas;
- (iii) the excessive waste of a gas which might be expensive or involve trouble in replacement.

Essentially the method consists of placing the counter (or other vessel to be filled) at the top of a Torricellian barometer, the gases being bubbled up through the mercury one at a time. The mercury thus prevents the first gas from getting down into the reservoir of the second gas and the partial pressures are readily observed (with simple corrections if the volume of the barometer tube is not negligible compared with that of the counter).

Initially all stopcocks (see figure) are closed and mercury is poured into the tank T until it is nearly full. Stopcocks S_1, S_8, S_6 and S_3 are then opened and the counter C and the flask F are evacuated, mercury rising in the barometer tube. S_1 and S_6 are now closed and S_4 and S_5 opened to introduce gas A into the flask F (and into the space between S_2 and S_3). S_4 and S_3 are now closed and S_2 opened. Mercury spills through S_2 to displace the gas between S_2 and S_3, which



Gas-mixing device

---

* Kodak Communication No. 1675H.

bubbles to the top of the system. (P is a splash trap to protect the counter from rising mercury.) S_2 is now closed and S_3 opened and the mercury between S_2 and S_3 spills to the bottom, coming to rest above S_7. The cycle: close S_3, open S_2, close S_2, open S_3, close S_3, . . . is then continued until sufficient of gas A has been passed up.

S_7 is then opened and the accumulated mercury drained out, air entering F. (The side tubes above S_7 are inclined to facilitate this.) S_7 is then closed, S_6 opened and F evacuated, whereupon the whole process is repeated with gas B and others if desired.

(Although the above process only takes a few minutes, it may be preferable to introduce the first—and perhaps more abundant—gas directly into C by a side-tube near S_1.)

Since the gas in F is compressed as mercury pours in, the initial reservoir A can be used even if it contains gas at pressure lower than that required in the final mixture. A modification which assists further in this direction is the attachment below S_7 of a rubber tube leading to a mercury reservoir which may be raised to compress the gas in F. As gas passes up through S_2 and S_3 mercury pours out of T and this tank may need replenishing occasionally. The final gas mixture will necessarily contain mercury vapour. Liquid air treatment will deal with this provided the boiling points of the gases used permit it.

I wish to thank Mr. S. Armstrong for making the device described and Professor C. J. Milner for helpful suggestions.

Apparatus for the production of a desired periodic flow in fluids

By V. R. Peterson, B.Sc., A.M.I.E.(Aust.), University of Sydney, Australia

[*Note received* 9 *June*, 1954]

In investigations of the nature and effects of fluctuating flow it is common to apply a pressure fluctuation of approximately sinoidal form, and often a periodic pressure of doubtful and complex waveform is used. The apparatus here considered is designed to produce flow variations of desired form as distinct from pressure variations.

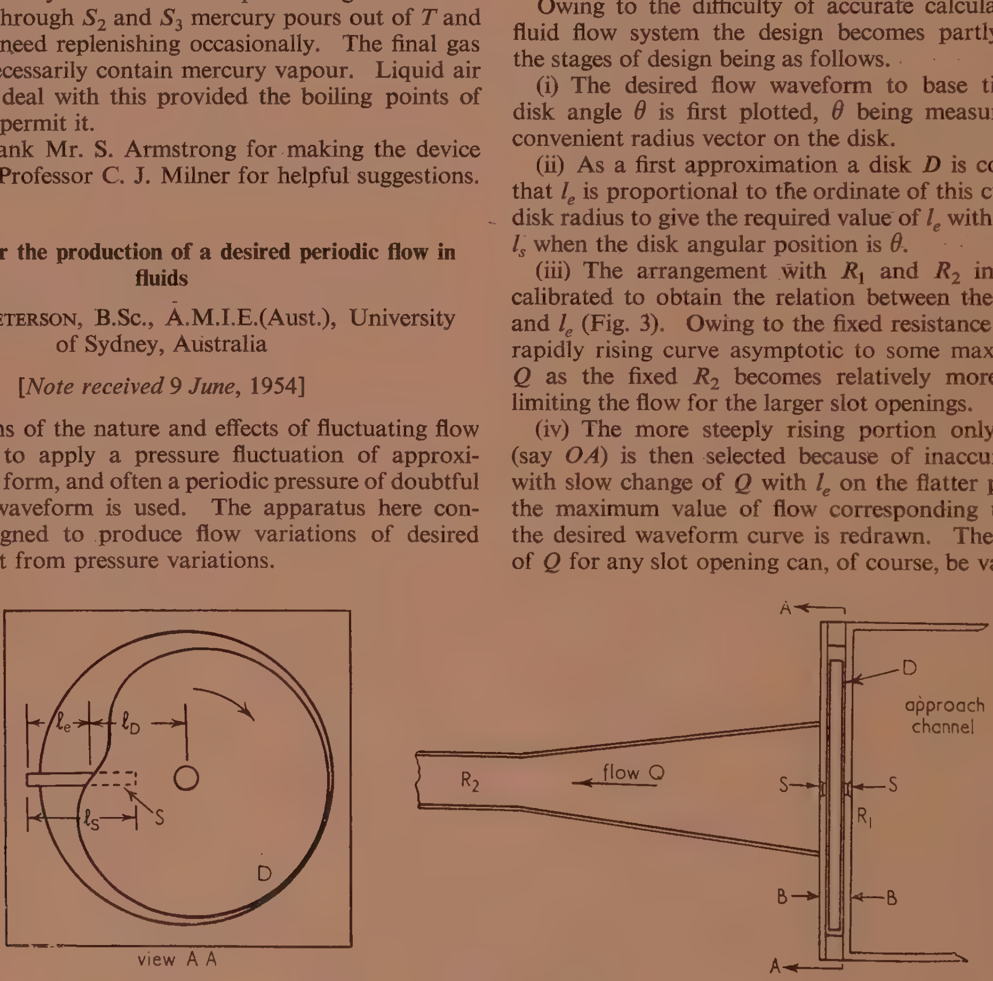


Fig. 1. Arrangement of disk and slots

Control of flow is provided by a gate (Figs. 1 and 2) consisting of a uniformly rotating disk D, the speed of which can be varied, flanked by two bulkheads B in which are cut identical narrow rectangular slots S. The double bulkhead and use of a small clearance reduce leakage past D which, as it rotates, varies the effective length l_e of the slot and hence controls the flow between any desired values.

The system is readily calibrated under static conditions when it consists of a constant head supplying the gate of variable resistance $R_1 = f(\theta)$ in series with the constant resistance R_2 of the rest of the system.

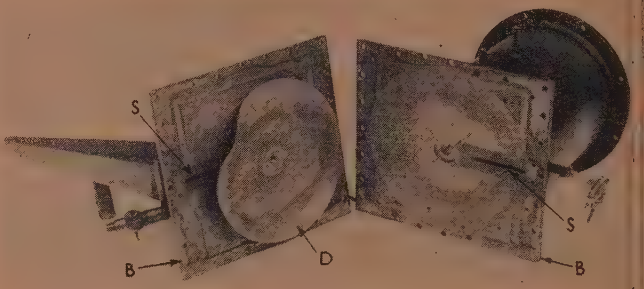


Fig. 2: Gate dismantled to show disk and slots

Owing to the difficulty of accurate calculation of such a fluid flow system the design becomes partly experimental, the stages of design being as follows.

(i) The desired flow waveform to base time and hence disk angle θ is first plotted, θ being measured from some convenient radius vector on the disk.

(ii) As a first approximation a disk D is constructed such that l_e is proportional to the ordinate of this curve. l_D is the disk radius to give the required value of l_e with a slot of length l_s when the disk angular position is θ.

(iii) The arrangement with R_1 and R_2 in series is next calibrated to obtain the relation between the actual flow Q and l_e (Fig. 3). Owing to the fixed resistance R_2 this gives a rapidly rising curve asymptotic to some maximum value of Q as the fixed R_2 becomes relatively more important in limiting the flow for the larger slot openings.

(iv) The more steeply rising portion only of this curve (say OA) is then selected because of inaccuracy associated with slow change of Q with l_e on the flatter portion. Using the maximum value of flow corresponding to the point A the desired waveform curve is redrawn. The absolute value of Q for any slot opening can, of course, be varied somewhat by adjustment of the slot width. This new waveform curve is now used in conjunction with the experimental $Q - l_e$ relationship to design a new disk which can then be mounted and the calibration checked.

The disk is not difficult to construct even for a relatively complex waveform. One constructed for use in the investigation of fluctuating flow through orifices to give a sinoidal ow of the form $a + b \sin \omega t$, did so with an error of less han 1% and showed little variation with frequency in the ommonly-used range up to a couple of hundred cycles per

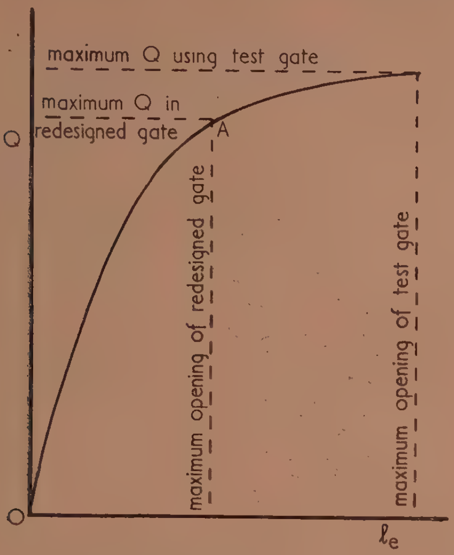


Fig. 3. Relationship between flow Q and slot opening l_e

inute. In order to minimize any variation with frequency e volume of fluid after the gate should be the minimum onsistent with the conditions of the experimental investi- ations.

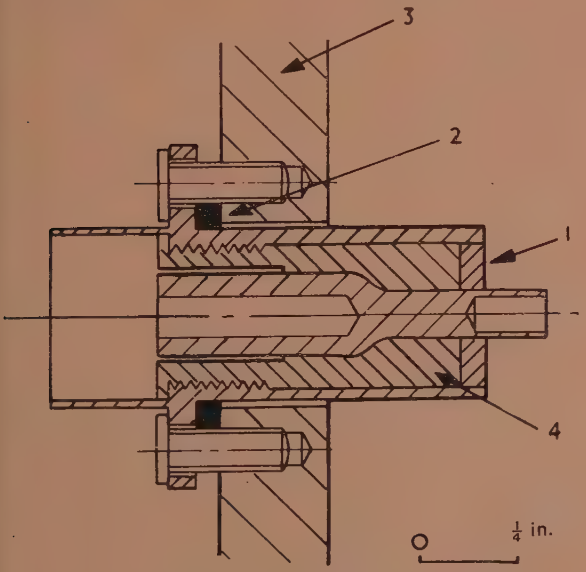
Coaxial cable termination vacuum seal

By E. E. Pesterfield and P. A. Einstein, Research Laboratory, Associated Electrical Industries Ltd., Aldermaston, Berks.

[*Note received* 2 *June*, 1954]

t is sometimes required to effect an external connexion with creened coaxial cable to some piece of equipment, such as a hotocell or Faraday cage housed in a vacuum. A simple odification to a coaxial terminal socket (type JS–1–PF by Films and Equipment Ltd.) adapts this to form a convenient vacuum junction. The insulating material is removed from the base of the socket to a depth of some $\frac{1}{16}$ in., preferably in a lathe. The space is then filled with casting Araldite type D (by Aero Research Ltd.) which forms the vacuum seal when set. The fixing holes are opened up to clear 6 B.A. screws and two flats filed on the outer thread. A black rubber ring, $\frac{7}{16}$ in. internal diameter × $\frac{1}{16}$ in. × $\frac{1}{16}$ in. cut out from sheet in the usual manner, seals the terminal to the wall of the vessel. The electrical insulating property of the terminal was found to be unimpaired by the application of Araldite.

The figure shows a cross-section of the modified terminal.



Modified terminal

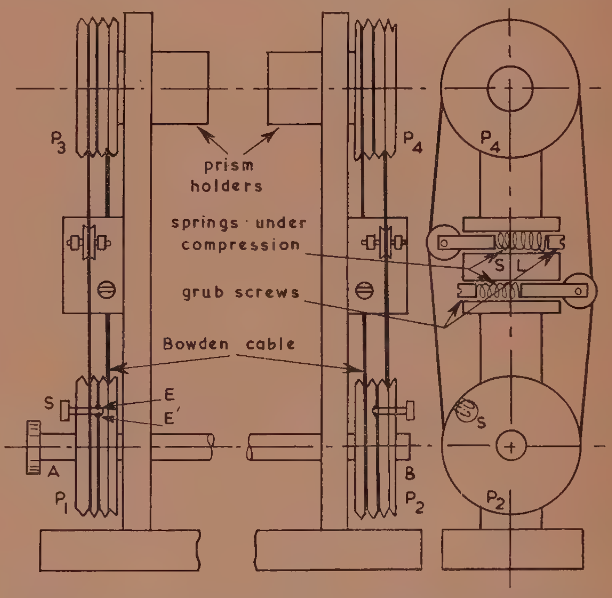
(1) Araldite; (2) rubber ring; (3) vacuum wall; (4) insulator.

A method for the simultaneous rotation of two polarizing prisms

By H. G. Jerrard, B.Sc., A.Inst.P., Physics Department, University of Southampton

[*Note first received* 21 *July, and in final form* 29 *August*, 1954]

It is often necessary to set two polarizing prisms to give extinction and then to rotate them simultaneously through at least 360° keeping the angle between their vibration directions fixed. In some applications the prisms cannot be connected by a rigid bar as in a petrographic microscope, but have to be mounted as shown in the figure with some connexion between the pulleys P_1 and P_2 on the rod AB, and the pulleys P_3 and P_4 on the holders of the prisms. In such an arrangement, used in flow birefringence studies, it was found that pulley belts of conventional type were not satisfactory because of the extreme accuracy required, and gear wheels (as used in the Dick microscope by J. Swift and Son Ltd.) were unsuitable because they did not allow any adjustment of height, gave backlash unless spring loaded, required considerable space and were costly. The arrangement described below gives the required accuracy, is compact and easy to construct.



Elevation and end view showing arrangement of pulleys and spring loading device for simultaneous rotation of two polarizing prisms

The four pulleys are identical in size and have threads of Whitworth-form turned on them. To connect the pulleys P_1 and P_3, one end E of a length of Bowden cable is inserted in a hole drilled along a radius of P_1. The cable is wound twice round the pulley in the V-grooves, then led to P_3 and after encircling this twice is returned to P_1 and the other end E' inserted in a hole adjacent to the end E. Both ends E and E' are securely fastened by a screw S. The length of wire EE' is made just long enough for the purpose and then put under tension by the spring-loading device SL shown in the figure: this eliminates backlash. The pulleys P_2 and P_4 are connected in an identical manner. In the arrangement used in this laboratory the pulleys have a diameter of 1·25 in. and have twenty-six threads per inch; the diameter of the cable is 0·018 in. The prisms may be rotated through about 680° with no change in their positions relative to one another. A larger rotation could be obtained by winding the wire more than twice round each pulley.

The accuracy of the method is shown by the following test. The polarizing prisms are accurately crossed by placing a very thin Soleil biplate (Nakamura plate)* between them and adjusting one prism in its holder until the field of view, as seen through an observation microscope focused on the dividing line of the biplate, is uniform. The eye is adapted to darkness for this test. The accuracy of setting is estimated† at 90 ± 0·01°. The prisms are clamped in their holders and then slowly rotated through 680° and back again. The field of view when observed through the microscope during the rotation shows no change, which indicates that the crossed setting is maintained.

This device is suitable for other applications. It is used in radio sets, e.g. when the graduated dial of a capacitor is brought out on the panel at a position not in line with the capacitor spindle. In the application described here, the optical nature of the rotating parts enables a very sensitive test of the accuracy of the method to be made: it is unlikely that this accuracy has ever been recorded.

Thanks are due to Professor A. M. Taylor, in whose department work on flow birefringence is continuing.

* Nakamura, S. *Zbl. Min. Geol. Paläont*, **6**, p. 267 (1905).
† Szivessy, G., and Münster, Cl. *Z. Phys.*, **53**, p. 31 (1929).

Balance with approximately logarithmic scale

By O. Kantorowicz, Dr.Phil., F.Inst.P., Parsons and Marine Engineering Turbine Research and Development Association, Wallsend, Northumberland

[*Note received* 5 *November*, 1954]

Cases are encountered where forces are to be measured not to an absolute accuracy, but to tolerances which are a certain fraction of the force. This applies, for instance, to the forces appearing on the brake of a torquemeter. Similarly, it is sometimes of importance to decide what is the order of magnitude of forces varying over wide limits. For instance, a postal balance must classify packets into weight categories with the following upper limits: ½, 1, 2, 4 . . . 16 oz, 2, 3 . . . lb. With this application in view the balances described below were devised some years ago but they have since found their main application in the laboratory for taking torque measurements. They proved themselves particularly useful for this task, as unlike the other balances tried, they did not oscillate and snatch even when used without a dashpot.

These balances consist essentially of a heavy disk (1) (Fig. 1), which has one or two circular tracks of large diameter, from which a flexible member (2) unwinds if a load is applied to it. The disk is equipped with two or one smalle circular bosses (3) on to which flexible members (4), by which the apparatus is suspended at (5), wind themselves if the disk is turning. The circular tracks are arranged so that their projections coincide at a point (6). To the centre of the disk (1) is fitted a rotatable pointer (7) which is held vertically by gravity and which plays over a scale (8) calibrated in suitable increments. As the disk (1) turns, the arm on which the load acts decreases, and the arm at which the centre of gravity (9) of the suspended system acts increases, with the result that for equal increments of load the increment in the angle of rotation, which leads to a new equilibrium position, decreases. The tracks having been made to coincide, the sensitivity drops to zero for large loads. The balance can therefore not unhook itself, even when shock-loaded. A further consequence of its non-linear characteristic is that it has no definite period of oscillation. This is believed to be the reason for its freedom from resonance. Fig. 2 gives a typical characteristic.

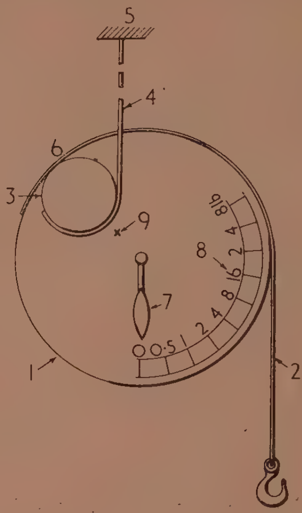


Fig. 1. General arrangement of balance

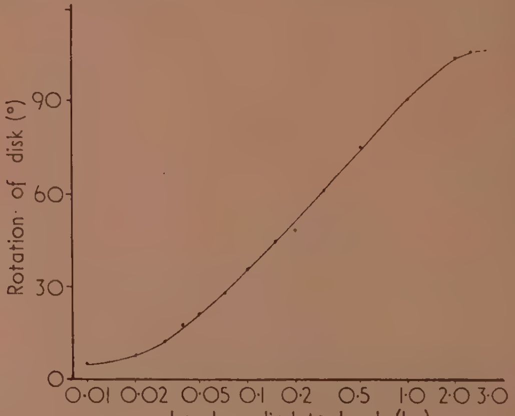


Fig. 2. Typical characteristic as taken. (Errors in placing scale marks and in measuring scale mark positions have not been smoothed out)

The first balances, made as postal balances, had an unfavourable ratio of maximum measurable load to their own weight (about 5 to 1). Later study models showed a ratio of 30 to 1 to be attainable.

Fig. 3 is a photograph of completed models. One of these hows a chain loop used as pointer. This eliminates parallax. oth sides of the disk can be equipped with scales, one of hich is then calibrated in kilogrammes and the other in unces and pounds.

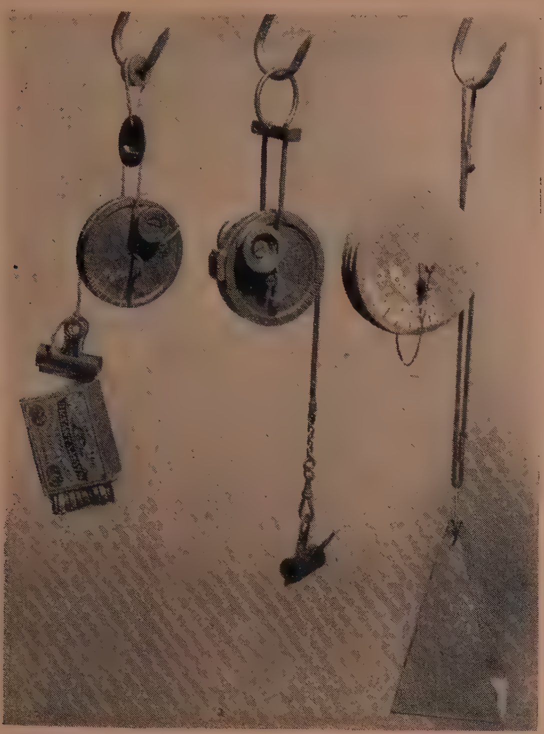


Fig. 3. Three study models of balance

daptation of a standard X-ray powder camera for work at low temperatures

By J. Thewlis, D.Sc., F.Inst.P., and A. R. Davey, Atomic Energy Research Establishment, Harwell, Berks.

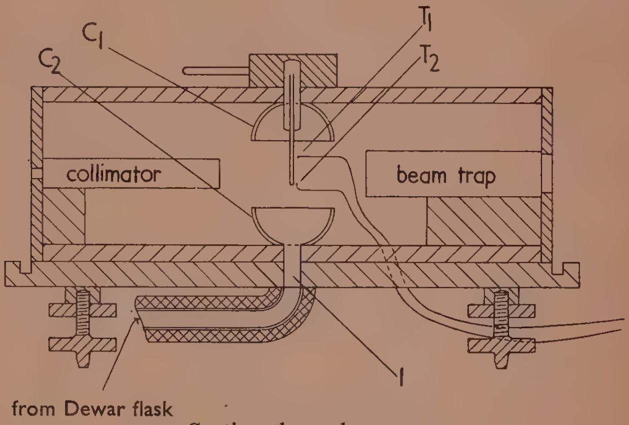
[*Note received* 8 *November*, 1954]

any accounts have appeared in recent years of the con-ruction of X-ray diffraction cameras for work at low emperatures. These mostly involve the making-up of a ompletely new camera and refrigeration system. The ollowing method is not claimed to differ greatly from some ready described, but it is simple and seems to be quite as ficient and accurate as many more elaborate systems. It ears obvious resemblances to the methods adopted by ume-Rothery and Strawbridge(1) and by Wallwork and arding.(2)

The specimen is cooled by a stream of gas obtained by oiling liquid nitrogen in a one gallon Dewar flask. This gas led *via* a lagged brass tube to a Unicam 19 cm camera here it plays directly on to the specimen, the temperature which is read by means of thermocouples. The camera is ontained within a double-walled box of insulating board; a ne and socket joint in the inlet tube and suitable fixed rminals for the thermocouple leads permit the camera to removed at any time with little effort. The scheme is own in the figure.

At the entrance of the inlet tube *I*, and around the top end the specimen, are fitted hemispherical celluloid caps C_1 d C_2, of diameter 2 cm. These serve to break up the gas w along the specimen and prevent the ingress of warm air. The boiling of the liquid nitrogen in the Dewar flask is achieved by the use of a 100 W immersion heater of nichrome wire, and the rate of boiling is controlled by a variable resistance. The flask is fitted with a tell-tale similar to that described by Geake.(3)

Chromel-*p*-alumel thermocouples, T_1 and T_2, are placed as close as possible to the specimen and just out of the X-ray beam, the leads being 0·025 cm in diameter. The ends of these leads are rigidly clamped to four heavy brass terminals fixed to the outside of the camera and to these terminals are connected the potentiometer leads whenever the camera is set up for an exposure. The mean of the two thermocouple readings is taken as the temperature of the specimen, the thermocouples being calibrated in terms of the spacings of a silver specimen, using the figures for the thermal expansion coefficient of that metal recently published by Owen and Williams.(4)



Section through camera

A word of warning should, perhaps, be given regarding the form of the specimen. It is found that a wire specimen, even when sealed off in the customary Pyrex or silica capillary tube, gains sufficient heat by conduction *via* the specimen holder to give rise to temperature discrepancies of up to 20° C, unless the wire is so short that its whole length is well away from the holder. With sealed-off powder specimens, on the other hand, no trouble is experienced, and such specimens are now used exclusively.

It is found that the temperature wanders during an exposure if not regulated, but with a little practice it can be held to within 1° C of the desired value. By the use of a suitable variable resistance, any temperature may be obtained between room temperature and −150° C.

It is unnecessary to stop an exposure when refilling the Dewar flask as the process takes only a minute or so. No trouble has been experienced from the freezing of moisture on or around the specimen or slit system, as, with the scheme described, there is automatically a slight excess pressure of dry gas in the camera at all times. It is found to be quite unnecessary to "flush through" with warm dry air before use or to take any other precautions against freezing.

REFERENCES

(1) Hume-Rothery, W., and Strawbridge, D. J. *J. Sci. Instrum.*, **24**, p. 89 (1947).
(2) Wallwork, S. C., and Harding, T. T. *J. Sci. Instrum.*, **31**, p. 163 (1954).
(3) Geake, J. E. *J. Sci. Instrum.*, **31**, p. 260 (1954).
(4) Owen, E. A., and Williams, G. I. *J. Sci. Instrum.*, **31**, p. 49 (1954).

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved products. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

Ballistic film analyser and recorder. Benson–Lehner Corporation, 2340 Sawtelle Boulevard, Los Angeles 64, California.

A machine for the semi-automatic measurement of the position of a reference mark in Cartesian co-ordinates is known as the Boscar Model A. One of its applications is the analysis of ballistic film records such as boresight data. It consists of a projector, a viewing screen and a control and measuring system. The projector is suitable for 16 mm and 35 mm film, and has a register pin movement which maintains a close film registration within ±0·0005 in. at the film plane. Unit or continuous frame advance is provided and speeds can be varied from one to twenty-four frames per second either forward or reverse. The screen has a usable area of 15 × 15 in. A single stick control is provided for moving the reference in the field of view. The position of the reference mark is measured in a Cartesian co-ordinate system by precision potentiometers suitable for parallel inputs into auxiliary equipment. A control is provided which will permit the output of the instrument to be reset to zero for any position of the reading reference so that the instrument may be set to zero with respect to fiducial or other reference marks. An automatic frame counter gives a visual indication up to 10 000 frames and has an output circuit for recording on an electrotyper. A ten-digit keyboard is provided for transferring digital information to an electrotyper. The makers state the accuracy of the measuring system to be ±0·1% of full scale deflexion.

Silvered mica capacitors. Johnson Matthey and Co. Ltd., Hatton Garden, London, E.C.1.

A new range of capacitors for applications where long-term stability is essential has recently been introduced. Three overall sizes from $1\frac{11}{16} \times 1\frac{1}{8}$ in. to $1\frac{1}{16} \times \frac{9}{16}$ in. are available. The capacitors, which are of fired construction, are rated at either 200 or 350 V peak working. Any value of capacity in the range 300 pF to $\frac{1}{4}$ μF can be supplied with a minimum tolerance of $\pm\frac{1}{2}\%$.

Multiple Geiger counter detector. The Radiac Co. Inc., 489 Fifth Avenue, New York, U.S.A.

This detector contains twenty-four Geiger counters and is intended for geophysical prospecting from a low-flying aeroplane, a moving vehicle, or on foot. The sensitivity of the cluster of twenty-four Geiger counters is stated to be adequate to locate deeply-buried deposits of uranium, oil-bearing stratigraphic traps and minerals such as gold, silver, copper and lead which are often associated with uranium in nature. The instrument is also stated to be capable of detecting radioactive clouds in the upper atmosphere. The instrument is supplied either with standard β–γ sensitive counters or bismuth-coated cathode Geiger counters. A compensator is provided which can be used to set the count to zero in a particular area, so that the instrument then registers count-rate increases over the background. A time-constant switch permits a selection of time-constants from 2 to 16 sec.

Research and laboratory microscopes. American Optical Co., Instrument Division, Buffalo 15, New York, U.S.A.

The No. 5 AO Spencer research microscope has been designed to produce a very flexible instrument. Monocular or binocular bodies may be fitted and there is a choice of two binocular bodies, one with parallel eye-tubes or one with converging eye-tubes. A novel means of obliquely illuminating the object can be supplied which is said to give three times more light for a given obliquity of illumination than that given by the more usual method of decentring the sub-stage iris diaphragm. The device consists of three bronze leaves which are rotated about a common axis at one end of each leaf thus closing the aperture from one side.

The Nos. 78 and 79 laboratory microscopes are similar but in the model No. 78 the eyepieces and objectives are locked in to prevent loss. The instruments are used facing the user so that stage and specimen are in full view.

Capacity test set. J. Langham Thompson Ltd., Bushey Heath, Herts.

The type 747C capacity meter is a direct-reading instrument for measuring capacities up to 250 pF. It operates as a transitron oscillator whose frequency is varied when the capacity to be measured is connected to the tuned circuit. The frequency shift is detected by a discriminator circuit which gives an output voltage proportional to capacity, and this voltage is applied to a valve voltmeter. The makers claim that once the zero and full-scale settings have been made the accuracy of calibration is maintained for many hours without re-adjustment. Full scale is set by switching a standard silver-mica capacitor across the tuned circuit to check the calibration of each range. Terminals are fitted to the front panel for connexion to the unknown capacity, and a probe is provided for taking *in situ* measurements of capacity in cables and wiring. In this case the shunt resistance may be as low as 10 kΩ without affecting the accuracy. The instrument has four ranges of 25, 50, 125 and 250 pF full scale, and an accuracy of 2% of full scale is claimed.

Automatic plotter of hysteresis loops. H. Tinsley and Co. Ltd., Werndee Hall, South Norwood, London, S.E.25.

An instrument for automatically plotting the hysteresis loop of magnetic materials has been designed to test ring specimens wound with the conventional H and B coils as used in ballistic testing. It consists of four units: an integrating recorder with a rectangular co-ordinate chart, 30 × 20 cm; an amplifier for operating the integrator from the e.m.f. induced in the B coil of the specimen; an amplifier operating the servo system driving the recorder H axis, which is in effect an automatic potentiometer measuring H; a unit automatically controlling the rate at which H is applied to the specimen.

The operation is entirely automatic when once started. A press button reverses the direction of H at any point so that minor loops can be taken anywhere on the cycle.

The instrument is capable of dealing with high permeability alloys such as mu-metal and HCR. The HCR alloy, with its almost vertical rise of B/H, has been found too difficult to record previously.* With this instrument no difficulty is found.

The integrating recorder may have other uses as it plots the time integral of any small e.m.f. of the order of a microvolt, against any variable voltage, which is automatically balanced.

---

* *Proc. Instn Elect. Engrs* 2, **101**, p. 417 (1954).

New books

nstrumental analysis. By John H. Harley and Stephen E. Wiberley. (New York: John Wiley and Sons, Inc.; London: Chapman and Hall Ltd., 1954.) Pp. vii + 440. Price 52*s*.

t is no new thing for analytical chemists to use physical nstruments as their legitimate tools. The viscometer, polarimeter and optical microscope have long had an onoured place in the analytical laboratory, whilst the eystone of the whole structure of classical gravimetric nalysis is that most elegant and precise of physical nstruments—the balance.

During the past two or three decades, however, instrumental analysis or "physical methods" has come to denote he application to chemical analysis of the newer techniques uch as emission and absorption spectroscopy, fluorimetry, polarography, conductimetry and X-ray diffraction. It is the widespread use of such methods which has brought about a minor revolution in the analytical laboratory, involving new ypes of equipment, often of a complex nature, and a staff of pecialists amongst whom may well be found physicists as well as chemists.

Dr. Harley and Professor Wiberley have produced an xcellent book, written primarily as a text for a course in nstrumental analysis given to senior and graduate chemistry tudents at Rensselaer Polytechnic Institute. It gives a etailed and up-to-date treatment of various aspects of pectroscopy including the Raman technique and flame hotometry, pH measurements, potentiometric and conuctimetric titrations, polarography, X-ray analysis (diffracon, emission, fluorescence and absorption), mass spectrometry and nuclear-radiation measurements. This systematic treatment of the subject should enable the student to obtain reasonably balanced picture of the limitations and advanages of these different methods of analysis. Teachers in other institutions should equally value the book as a guide to planning similar courses for the instruction of the newer eneration of analysts.

To English readers it is perhaps some disadvantage that he commercial instruments described are almost entirely of American manufacture, but this is hardly surprising. The minutiae of manipulation, however, is but a minor theme and properly subordinated to discussions of the theory, the principles of instrumentation, and typical procedures and applications.

B. S. Cooper

Fertigungs- und stoffgerechtes Gestalten in der Feinwerktechnik. By K. H. Sieker. (Berlin: Springer-Verlag, 1954.) Pp. v + 166. Price DM21.

Verbindungselemente der Feinwerktechnik. By H. Pöschl. (Berlin: Springer-Verlag, 1954.) Pp. v + 108. Price DM13.50.

These are two recent additions to a series of German nstructional manuals describing modern workshop techniques n mass production of engineering components. The first discusses the various methods of shaping a wide range of materials to pre-determined forms and their most advantagous applications to quantity production of typical components. The second manual deals with fastening devices and methods for fixing separately-made parts of an assembly irmly together. Both are profusely illustrated with drawings and the former contains much tabulated information abstracted from the appropriate DIN specifications.

H. Barrell

Chemical engineering instruments and control methods. General Editor: E. Molloy. (London: George Newnes Ltd., 1954.) Pp. x + 182. Price 21*s*.

Written by some dozen separate authors the several sections of this book include general descriptions of pH meters, spectrophotometers, photoelectric instruments, liquid level indicator, pneumatic control instruments, ultrasonic equipment, etc. Though the title might well be thought to indicate a comprehensive treatise on all chemical engineering instruments, yet some of the most common measurements of all, namely temperature, flow and weight, are, surprisingly, almost completely absent from the text.

Although a few of the sections cover a wide view of the subject being discussed, many are limited to descriptions of instruments manufactured by the firm with which the particular author is associated.

A. J. Maddock

The design and use of instruments and accurate mechanism. By T. N. Whitehead. (New York: Dover Publications, Inc., 1954.) Pp. xiv + 283. Price $3.95 cloth; $1.95 paper.

Books dealing with the principles of kinematic design are few and far between. This reprinting of one, originally published in 1934, that had become difficult to obtain in recent years is therefore much to be welcomed. Part I develops a theory of instrumental errors which is essentially non-mathematical in origin. In Part II this theory is applied to a variety of typical mechanisms illustrated by examples which now look somewhat old-fashioned but which remain extremely suitable for the author's purposes. One important theme developed is that mistakes in design are due to redundant elements or over-constraint. It is certain that all those interested in studying the proper design and use of instruments and accurate mechanism will benefit much from reading this book.

H. Barrell

Electronic measuring instruments. By E. H. W. Banner, M.Sc., F.Inst.P. (London: Chapman and Hall Ltd., 1954.) Pp. xiv + 395. Price 45*s*.

It would seem that this book can best be considered as in the nature of a catalogue of measuring instruments employing electronic devices, each one treated briefly and serving as an introduction to the application of electronics to measurement of various quantities. Most of the instruments described are commercially available and some of the sections centre around a particular manufacturer's product.

The first part is devoted to short descriptions of electronic devices—hot- and cold-cathode valves, cathode-ray tube, photoelectric devices, rectifiers, and radiation and particle detectors. Instruments using these devices are then outlined and also included are such related devices as magnetic amplifiers and semi-conducting elements.

Assistance is acknowledged for contributions by other writers, some of whom have written a chapter or section. This has obviously helped considerably in the compilation of the volume but leads to a certain patchiness in style. The chapters dealing with radiation detectors and instruments are particularly lucid, but a newcomer to electronic instruments may have difficulty in comprehending the last two chapters dealing with "electrical instruments" and "instruments for physical quantities," the descriptions in which are not as clear as they might be.

A. J. Maddock

Notes and comments

Elections to The Institute of Physics

The following elections have been made by the Board of The Institute of Physics:

Fellows: F. I. Hurley, A. J. Kennedy, J. D. McGee, M. E. Pillow, A. Radcliffe, H. C. von Bertele.

Associates: M. E. Baird, G. A. Bassett, S. S. Baxter, W. R. Blevin, J. S. M. Botterill, D. S. Briggs, E. S. Brown, W. F. Caplehorn, G. K. Eaton, R. W. M. Fane, G. G. Fowlie, R. Gill, D. Greene, S. Griffith, W. D. Hardy, A. K. Head, J. F. Hills, K. R. Hodgson, S. B. Hudson, I. H. Jenkins, Y. Klinger, J. Laby, D. H. Le Croissette, S. N. A. Margerson, R. H. Norman, P. G. Parish, W. D. Parkinson, N. J. C. Peres, A. G. N. Pulford, J. M. Rooke, H. B. Sarjeant, G. R. Sharp, S. E. F. Smallwood, F. Smith, J. A. S. Smith, A. M. A. Swindells, K. E. Timmel, R. Vollprecht, B. R. H. Warrell, C. G. Webb, F. J. Weinberg, R. E. Weston, W. S. Whitlock.

Forty-six Graduates, eighteen Students and seven Subscribers were also elected.

Luminescence with particular reference to inorganic phosphors

The proceedings of a symposium held by the Electronics Group of The Institute of Physics in Cambridge in April 1954 have now been published as Supplement No. 4 to the *British Journal of Applied Physics*. Twenty-three papers are included together with summaries of the discussions on them. This symposium, in which the emphasis was upon solid inorganic phosphors, was the first important meeting on this subject since 1938. Its significance is indicated by the fact that one-third of those attending had come specially for this purpose from oversea, eight foreign countries being represented.

The supplement opens with Dr. S. T. Henderson's survey of the development of luminescence since 1938. Among the papers are the following which indicate the range of aspects of luminescence that were discussed: The investigation of new phosphors, with special reference to pyrophosphates; The mechanism of electroluminescence of zinc sulphide; The physical chemistry of sulphide phosphors; Atomic configurations in luminescent centres; Theory of activator systems in luminescent solids.

Additional copies of this supplement, bound in stiff covers, may be obtained from the publishers: The Institute of Physics, 47 Belgrave Square, London, S.W.1, price 25*s.* (including postage).

Harwell Isotope School

The Harwell Isotope School, which since it was founded in 1951 has had 329 students from 29 different countries, is now preparing its programme for the next twelve months. Training is given at this school in the applications of radioactive materials in research and industry and in the techniques of producing, measuring and handling such materials. The courses, which last for four weeks, include both lectures and practical work in the laboratory. Students should be graduates of a university. Courses commence on 25 April and 27 June, 1955. Details of the course fee and further information can be obtained on application to The Isotope School, Atomic Energy Research Establishment, Harwell, Berks.

Errata

In the paper "A phonic wheel generator for position indication in digital computer magnetic drum storage" by D. R. Quested and A. D. Booth, published on p. 357 of the October 1954 issue of this *Journal*, the reluctance values mentioned under equation (9) are derived from equation (2) and not from equation (9) as stated. In Fig. 3 the units of the velocity scale should be ft/sec.

British Journal of Applied Physics

Contents of the February issue

ORIGINAL CONTRIBUTIONS

Some dynamic mechanical properties of polyisobutylene over a wide temperature range. By D. A. Thomas and D. W. Robinson.
Some properties of a simple omegatron-type mass spectrometer. By A. G. Edwards.
The physical and computing significance of an electrical analogue of creep and recovery. By A. J. Kennedy.
The field due to an infinite dielectric cylinder between two parallel conducting planes. By C. Mack.
Growth of the barium orthosilicate interface of oxide-coated cathodes. By M. G. Harwood and N. Fry.
Phase and amplitude balance methods for permittivity measurements between 4 and 50 cm. By T. J. Buchanan and E. H. Grant.

NOTES AND NEWS

Correspondence

Probe impedance in the electrolytic tank. From J. C. Burfoot.
Electrical dehydration of tar emulsions. From H. A. Howe and C. A. R. Pearce.

New books

Notes and comments

Journal of Scientific Instruments

Original contributions accepted for publication in future issues of this Journal

A thermocouple anemometer. By R. F. Benseman and H. R. Hart.
The measurement and display of the current gain of a transistor as a function of emitter current. By R. A. Hilbourne.
A dielectric heating unit for the study of sand properties at elevated temperatures. By R. Rew and R. G. Godding.
A generator for very small direct currents. By K. D. E. Crawford.
The theory and design of rotating mirror cameras. By H. Edels and D. Whittaker.
A simple method of measuring the dynamic Young's modulus of concrete. By J. P. A. Lochner and W. de V. Keet.
An apparatus for measuring the elastic properties of gels. By L. J. Hastewell and R. Roscoe.
A modified pocket integrating ion chamber type B.D. 11 of nearly uniform polar response. By B. W. Soole.
Apparatus for measuring the intensity of cosmic radiation at great depths in the sea. By J. C. Barton.
A high-temperature, powder, X-ray camera and diffraction patterns of Ceylon graphite at 1800° C. By Eitaro Matuyama.
A simple, dynamic, leak detector. By T. B. Kent.
An adiabatic calorimeter for measuring the specific heats of liquids in the range 0 to 100° C. By L. W. Phipps.
A simple, sensitive, saturated core, recording magnetometer. By V. B. Gerard.
A microscope hot-stage using electron bombardment. By G. J. Ogilvie and G. Brinson.

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principles, construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Square, London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation of contributions*. (Price 2*s.* 6*d.* including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon application from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, London, E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within 60 days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of address or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £4 per volume ($11.50 U.S.A.), including index (post paid) payable in advance. Single parts, so far as available, may be purchased at 8*s.* each ($1.15 U.S.A.), post paid, cash with order. Orders should be sent to The Institute of Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

The measurement and display of the current gain (α) of a transistor as a function of emitter current

By R. A. Hilbourne, B.Sc., The General Electric Co., Ltd., Wembley, Middlesex

[*Paper first received* 26 *August, and in final form* 1 *December*, 1954]

An apparatus for displaying, on a cathode-ray oscilloscope, the variation of the current gain α of a point-contact transistor is described. The design of this apparatus is discussed with particular reference to the amplifier bandwidth requirements that are necessary to display accurately the rapid variations in α. The displayed curves for a typical point-contact transistor over various ranges of emitter current are given.

treating a transistor amplifier as a four-terminal linear- tive network it is possible to define its electrical behaviour terms of four parameters (which can be chosen in a variety ways).(1,2) One of the most important of these parameters the current gain α, which is defined as the rate of change of llector current with change of emitter current at a constant llector voltage

$$\alpha = \delta I_c/\delta I_e$$

$$V_c = \text{constant}$$

owever, this current gain is not constant but is very pendent upon the d.c. bias conditions. This is especially ue of point-contact types in which variations of emitter rrent produce very marked changes in α.

A knowledge of these variations in current gain is of great nportance in designing transistor circuits. The unit described, hich displays on a cathode-ray oscilloscope the variation of as a function of emitter current, was designed as a simple ece of test gear for use in a transistor applications laboratory well as for production checking of transistors.(3,4)

PRINCIPLE

The basic system is shown in the block diagram of Fig. 1(*a*). he emitter current bias is varied sinusoidally at 50 c/s. In rder to observe the variation of transistor current gain with nitter bias current a small amplitude (but constant current) kc/s signal is superimposed on the emitter and the sulting 50 kc/s collector current is measured; by displaying e 50 kc/s collector current on the Y-plates of an oscilloscope, d the 50 c/s emitter bias current on the X-plates, the riation of transistor current gain with emitter bias current obtained.

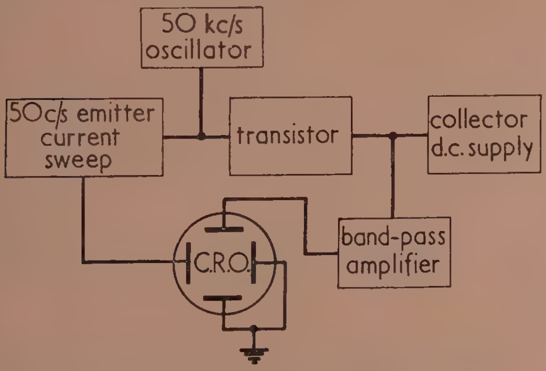


Fig. 1(*a*). Block diagram of the general circuit arrangement

DESIGN OF EQUIPMENT

50 kc/s measuring circuit. The value of α is measured by injecting a small 50 kc/s signal current, from a constant current source, into the transistor emitter. The resultant collector current is obtained by measuring the voltage developed across a small choke, which is in series with the collector. The α-measurement is calibrated by applying the signal current directly into the choke which is then in parallel with the output impedance of the transistor.

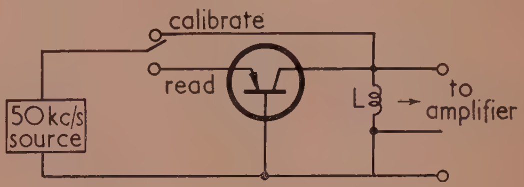


Fig. 1(*b*). Transistor 50 kc/s circuit (all bias circuits omitted)

Thus for "calibration" position as shown in Fig. 1(*b*), with a peak input signal current i_s, the voltage measured is given by

$$V_{CALIBRATION(peak)} = \frac{i_s \times j\omega L \times R_{output}}{j\omega L + R_{output}}$$

where L is the inductance of the collector load, R_{output} is the output impedance of the transistor (with emitter/base a.c. open circuit) and ω is the angular velocity of the applied signal.

In the "read" position the signal is applied to the emitter and the voltage developed across the choke L, as the collector load, is measured. This voltage is given by

$$V_{READ(peak)} = i_s \times \alpha \times j\omega L \times \frac{R_{output}}{R_{output} + j\omega L}$$

where α is the true current gain measured with the collector short circuit to a.c.

Thus the ratio

$$\frac{V_{READ}}{V_{CALIBRATION}} = \alpha\,(true)$$

and is not the current gain modified by the collector load. Therefore, there is no limitation on the value of the output impedance of the transistor to be measured, except that it must be positive. [With a negative output resistance the collector choke oscillates with the decoupling capacitor; this blocks the amplifier. The effect of this negative output resistance is shown in Fig. 2 (p. 87).]

The calculations all assume that the 50 kc/s signal current is constant and unaffected by the input impedance of the transistor emitter. To ensure this constant current, the 50 kc/s signal is fed through a 1 MΩ resistance, which limits the maximum value of the input impedance of the transistor for accurate measurements. This input impedance is further limited by the shunting effect of the emitter sweep supply series resistor which, for the low emitter current ranges (when the emitter input impedance is highest), is 1 MΩ. Thus for 1% accuracy the input impedance must be less than 5 kΩ.

The emitter current sweep circuit. As shown in Fig. 3, the emitter sweep current is obtained by half-wave rectification of a 500 V peak 50 c/s a.c. voltage which is applied across a potential dividing chain (R_1 to R_5). The current range required is obtained by connecting the emitter *via* switch S_3 through a high resistance to various tapping points on this dividing chain. For the highest current ranges this high resistance is 100 kΩ and for the lower ranges 1 MΩ. Thus if the input impedance of the transistor is less than 1% of this value the emitter current is proportional (1% accuracy) to the voltage obtained from the dividing chain. This voltage is applied to the oscilloscope X-plates to give a deflexion proportional to the emitter current.

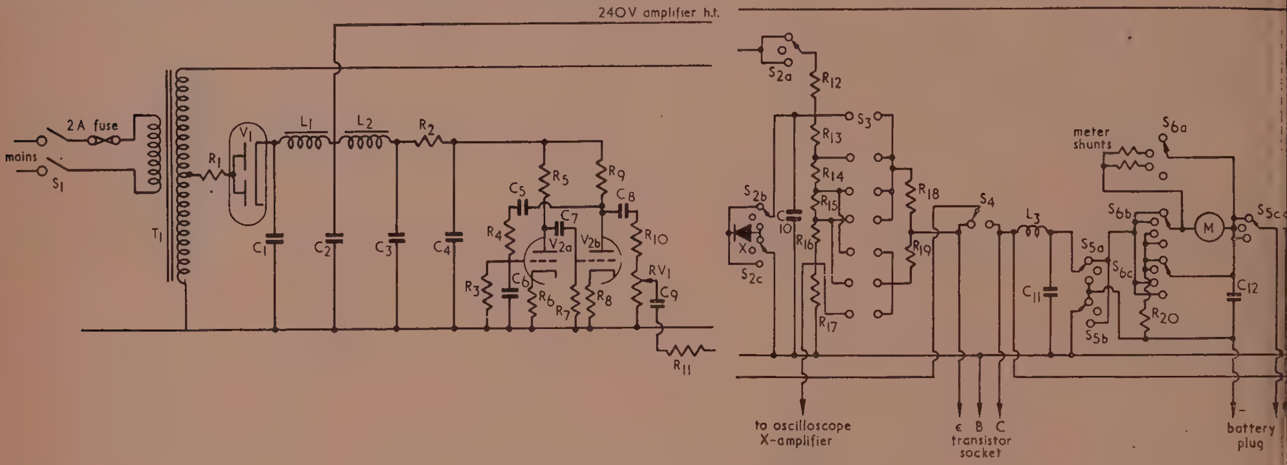


Fig. 3. Circuit diagram of the complete equipment

Band width considerations. As the emitter current is swept, the transistor current gain varies; thus the 50 kc/s voltage developed across the collector choke is modulated in amplitude. In order that the modulation envelope be displayed without distortion, the amplifier must have a flat frequency response over the frequency range

$$f\,osc. \pm f\,mod.$$

where $f\,osc.$ is the frequency of the search oscillator (50 kc/s) and $f\,mod.$ is the maximum modulation frequency. However, the lower frequency collector current waveform produced by the 50 c/s emitter sweep must be rejected; this requires that the amplifier has a high pass characteristic.

Although the time taken by the emitter current to go from zero to peak value is $\frac{1}{200}$th of a second, the initial velocity of this sweep is higher than the mean velocity, where the mean velocity V_m is given by

$$V_m = 200D \text{ cm/s}$$

where D is the total length in centimetres of the display sweep.

The rapid variations of α with emitter current invariably occur in the initial range of the scan (i.e. at low values emitter current). In order to estimate bandwidth requi ments, it is thus necessary to assume that the emitter curre is being scanned at the initial scanning velocity. Since t scanning waveform is sinusoidal, the initial scanning veloci V_i is given by

$$V_i = \frac{\pi}{2} V_m = 100\pi . D \simeq 300D \text{ cm/s}$$

Suppose it is required that α be allowed to rise from zero peak value over a length of scan equal to 2% of the to scan length (i.e. in a distance 0·02D). The time (t_r) tak for this, assuming that the velocity is V_i, is given by

$$t_r = \frac{0{\cdot}02D}{300D} \simeq 7 \times 10^{-5} \text{ s}$$

If it is now assumed that this time t_r corresponds to the ti taken by a sinusoidal modulating signal to go from minimu to maximum value, it is seen that the frequency, $f_{mod.}$, such a signal would be given by

$$f_{mod.} = \frac{1}{2 \times 7 \times 10^{-5}} \simeq 8 \text{ kc/s}$$

It is therefore seen that the ±15 kc/s bandwidth of t amplifier used is suitable for displaying very rapid variatio of α.

The output from the high-pass amplifier is fed direct into the oscilloscope Y-amplifier; thus the α *versus* i_ε cur appears as the modulation envelope of the 50 kc/s signa It was felt that no advantage would be gained by demod lating the 50 kc/s output signal and that it might well lea to unnecessary complication of the circuit. The oscillosco waveforms, as obtained with a typical point-contact transist for various values of emitter current sweep, are shown Fig. 4(a to g) (p. 87).

CIRCUIT ARRANGEMENT

Scanning circuit. The power supply provides 240 V d high tension for the oscillator and amplifier and a 700 V pea 50 c/s voltage for the emitter sweep supply. The circuit use has the disadvantage that the surge-charging current for t d.c. supply produces a kink in the sine wave applied to t emitter, which has high-frequency components; these com ponents could pass through the band-pass amplifier. Th undesirable effect is eliminated by putting a small resistan in series with the rectifying value to limit the surge curren

0·1 μF capacitor in the sweep supply circuit also helps liminate the high-frequency components.

50 *kc/s oscillator circuit.* A two-valve resistance-capacitance eedback oscillator is used to generate the 50 kc/s search urrent; this gives a maximum peak current of 4 μA into the MΩ output series resistor.

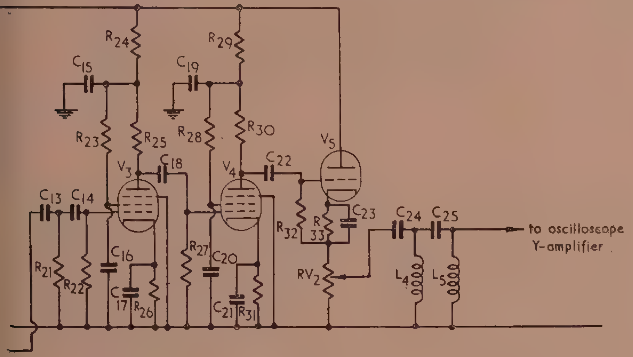
Band-pass amplifier. The band-pass amplifier consists f a double resistance-capacitance high-pass filter feeding nto two stages of a low-noise pentode amplification which is ollowed by a cathode follower and a double inductance-apacitance high-pass filter. This gives a frequency response s shown in Fig. 5, this is flat over the range 30–70 kc/s measured by applying a constant current input into the ollector choke) and attenuates frequencies below 15 kc/s. The gain over the pass-band is 4 V/μA in the choke.

that the current sweep range is in each case equal to a 10 V d.c. deflexion along the X-axis of the oscilloscope.

Oscilloscope. The oscilloscope must have a d.c. coupled X-amplifier with a sensitivity of 10 V d.c. for full tube deflexion while the Y-amplifier, which is a.c.-coupled, must give a full deflexion for a 2 V peak-to-peak signal and have a flat frequency response over the range 30–70 kc/s.

OPERATING PROCEDURE

To use the equipment, the bias controls are switched to the off position, the amplifier gain turned to zero and the oscilloscope spot shifted to the zero position on the graticule. Then, with the transistor inserted, the appropriate bias conditions are applied. The amplifier gain and oscillator output are adjusted with switch S_4 in the "calibrate" position, such that the rectangular waveform extends from the -1 to $+1\alpha$ graticule lines. On switching to the "read" position the α-waveform can be read directly from the graticule. For emitter currents greater than 10 μA the accuracy is limited by the oscilloscope display to ±5%, but below 10 μA the increase in emitter resistance introduces a further error, giving an accuracy of ±10% down to 2 μA of emitter current.



R_{13} to R_{19} = 1% high stability resistors
R_1 = 330 Ω
R_2 = 47 kΩ
R_3 = 2·7 kΩ
R_4 = 1 kΩ
R_5 = 18 kΩ
R_6 = 5·6 kΩ
R_7 = 470 kΩ
R_8 = 3·3 kΩ
R_9 = 22 kΩ
R_{10} = 470 kΩ
R_{11} = 1 MΩ
R_{12} = 17 kΩ
R_{13} = 25 kΩ
R_{14} = 15 kΩ
R_{15} = 7·5 kΩ
R_{16} = 1·5 kΩ
R_{17} = 1 kΩ
R_{18} = 100 kΩ
R_{19} = 1 MΩ

R_{20} = 10 kΩ
R_{21}, R_{22} = 47 kΩ
R_{23} = 470 kΩ
R_{24} = 10 kΩ
R_{25} = 100 kΩ
R_{26} = 1 kΩ
R_{27}, R_{28} = 470 kΩ
R_{29} = 10 kΩ
R_{30} = 100 kΩ
R_{31} = 1 kΩ
R_{32} = 470 kΩ
R_{33} = 2·2 kΩ

RV_1 = 1 MΩ
RV_2 = 10 kΩ

C_1 = 8 μF
C_2 = 16 μF
C_3, C_4 = 8 μF
C_5 = 220 pF
C_6 = 330 pF

C_7, C_8, C_9 = 0·01 μF
C_{10} = 0·1 μF
C_{11} = 2 μF
C_{12} = 50 μF
C_{13}, C_{14} = 0·001 μF
C_{15} = 8 μF
C_{16} = 4 μF
C_{17} = 25 μF
C_{18} = 0·001 μF

C_{19} = 8 μF
C_{20} = 4 μF
C_{21} = 25 μF
C_{22} = 0·01 μF
C_{23} = 25 μF
C_{24}, C_{25} = 0·0047 μF

V_1 = U78
$V_{2a,b}$ = B309

V_3, V_4 = Z729
V_5 = L77

L_1, L_2 = 20H
L_3 = 2 mH
L_4, L_5 ≃ 25 mH

T = 0–250–500 V, 100 mA transformer
M = 1 mA meter

S_1 = 2-pole, 2-way
S_2 = 3-pole, 3-way
S_3 = 2-pole, 7-way
S_4 = 1-pole, 2-way (break before make)
S_5 = 3-pole, 3-way
S_6 = 3-pole, 4-way

X = 500 V, 50 mA selenium rectifier

Fig. 3 (*continued*). Circuit diagram of the complete equipment

Switches. The transistor collector d.c. bias and emitter weep are controlled by switches S_2, S_3, and S_5, while S_4 witches the 50 kc/s signal from collector to emitter thus iving the "calibrate" and "read" positions. The meter ange is controlled by switch S_6, giving two ranges of i_c 1 and 10 mA) and two ranges of v_c (10 and 50 V).

Sweep current ranges. The bias sweep dividing chain gives even sweep ranges from 10 μA to 5 mA; a tapping point is onnected to the d.c. X-amplifier of the oscilloscope such

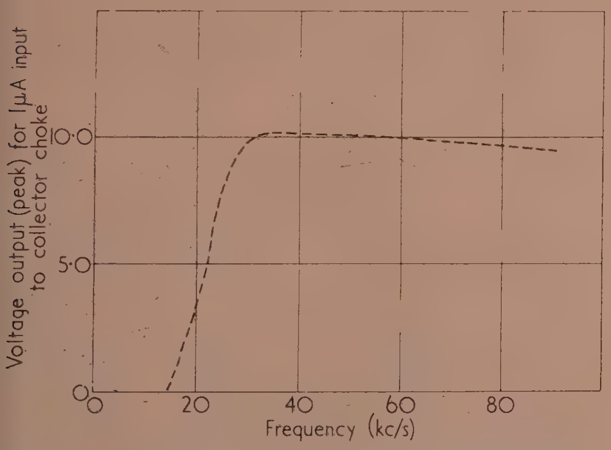


Fig. 5. Frequency response of the band-pass amplifier for constant current input

This apparatus has been found very useful as a quick check of point-contact transistor characteristics as well as for a detailed study of large quantities for production purposes.

The apparatus has also been used for displaying the variations of α_{cb} with base current for junction transistors, but it has the disadvantage that the 50 kc/s signal is beyond the α_{cb} cut-off frequency for most transistors manufactured at the present time; hence the results obtained do not necessarily apply over the usable frequency range which is limited to about 10 kc/s. Any decrease in the search current frequency, however, would require a lower sweep current frequency and a much more elaborate apparatus.

REFERENCES

(1) Ryder, R. M., and Kircher, R. J. *Bell Syst. Tech. J.*, **28**, p. 367 (1949).
(2) Sittner, W. R. *Proc. Inst. Radio Engs*, **40**, p. 448 (1952).
(3) Morrow, W. E. *Measurement of Transistor Parameters by C.R.O. and other means*, Convention record of the Institute of Radio Engineers, Part 9, p. 45 (1953).
(4) Cooke-Yarborough, E. H., Florida, C. D., and Stephen, J. H. *Proc. Inst. Elect. Engrs*, **73**, p. 288 (1954).

A reflexion electron microscope

By V. E. Cosslett, Ph.D., F.Inst.P., and D. Jones, Ph.D., Cavendish Laboratory, Cambridge

[*Paper received* 9 *August*, 1954]

The design, construction and performance are described of an apparatus specially built for microscopy of solid surfaces which are illuminated by an electron beam at grazing incidence. General requirements of design are discussed as well as practical details. Special features are: a continuously variable tilt of the illuminating system from 0 to 10°; an object stage possessing several degrees of freedom; and an objective lens of long working distance which allows specimens to be examined of a size usual in metallurgy, and permits them to be subjected to heat or other treatment, since they are outside the lens pole piece. The magnification is continuously variable from ×500 to ×10 000. Electron diffraction patterns can also be obtained without changing the position of the specimen; the lens system is designed so as to minimize the distortion, rotation and chromatic errors in diffraction patterns. Typical micrographs are shown of both ferrous and non-ferrous metals, and difficulties in the interpretation of reflexion pictures are briefly discussed.

In the transmission electron microscope the examination of surfaces or of structure revealed superficially by polishing and etching is indirect, involving as an extra stage a replica which is liable to introduce its own limitations and errors. Several workers have attempted to develop the methods of direct electron imaging which might replace or complement the replica technique. Thus the work of Ruska and Müller,(1) and von Borries,(2) has been followed up in Russia,(3) in France,(4) and in England;(5,6,7) a high voltage scanning microscope has been developed by McMullan(8) and a secondary emission microscope by Möllenstedt and Duker.(9)

In this paper the electron microscope designed at the Cavendish Laboratory, primarily for studying surfaces by reflexion, will be described.

GENERAL CONSIDERATIONS

There are certain features of design which distinguish an electron microscope used for reflexion work from the instrument used in transmission.

(1) The mechanism used for alining the illuminating system must permit the axis of that system to be inclined at an angle of several degrees to the axis of the objective lens. It may, most simply, comprise a wedge inserted between the objective and condenser lenses but it is preferable to be able to increase the inclination continuously.

(2) The object stage must be capable of accommodating massive objects if normal metallurgical specimens are to be examined and it must possess more degrees of freedom than are required in transmission microscopy.

(3) A long working distance in the objective lens is unavoidable when the pole piece is designed to allow the specimen to be placed clear of its top surface. Under this condition it is not possible to reduce the focal length or chromatic aberration constant C_c of the lens appreciably below 0·5 cm, and since the proportional energy spread $\Delta V/V$ of the electrons scattered from a surface is about 1 : 800 for a voltage of 50 kV, the resolution of the microscope, given effectively by

$$\delta_c = C_c . \alpha . \Delta V/V$$

(α = the semi aperture angle of the objective lens), is limited to about 400 Å. For transmission microscopy focal lengths of less than 1 mm have been used, the object being placed in the pole piece gap, but such a solution is not readily applicable to reflexion micr scopes—the immersion of the object in the magnet field would prohibit the examination of ferrous spec mens, the difficulty of constructing a specimen stag would be considerable, and the deviation of the no axial illuminating beam by the objective lens fie would be undesirable.

(4) In transmission electron microscopes an objecti aperture is inserted to improve image contrast; it essential to resolution in reflexion microscopy.

Two other properties desirable in reflexion microscopes bu not characteristic are:

(5) the capacity for obtaining diffraction patterns from selected microregion of the specimen;

(6) a continuous magnification range descending to ×50 to facilitate direct comparison of the electron micro graphs with optical micrographs. Since reflexio microscopy provides a series of profile views of surface it is obviously complementary to a techniqu which furnishes plan views.

DESCRIPTION

A simplified elevation and sectional view of the microscop is shown in Fig. 1.

Gun. The electron gun *A* is conventional and is designe to operate at 30–90 kV. The filament (3) (Fig. 2) may b adjusted in three dimensions with respect to the bias shield (4 and the combined unit (1) may be displaced horizontally b the screws (5) with respect to the anode (6). The gun is sel biased and the bias resistor is variable in six steps. A glas cylinder (7) isolates that part of the microscope at hig voltage. The gun delivers illumination via the condense lens *B* to the specimen in the object chamber *E*.

Lenses. By using three imaging lenses *F*,*I*,*K* (Fig. 1 magnifications of ×500–×10 000 may be obtained, though fo reflexion work the low intensity of the scattered beam an the need to reduce the size of the objective aperture in orde to minimize the chromatic aberration combine to limit th useful direct magnification to about ×3000. It is possib to obtain diffraction patterns from a specimen by adjustin the intermediate lens *I* to focus at the object plane of th projector the pattern existing in the back focal plane of th objective lens, and the region of the specimen forming th pattern may be limited by inserting an aperture *H* abov the intermediate lens in a plane conjugate with the specime

The measurement and display of the current gain (α) of a transistor as a function of emitter current

By R. A. HILBOURNE, B.Sc.

See pages 83–85

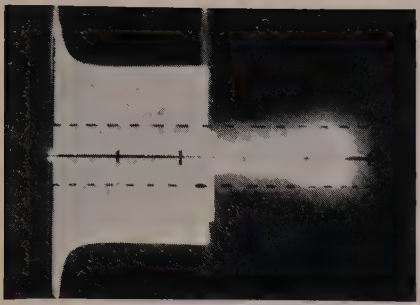
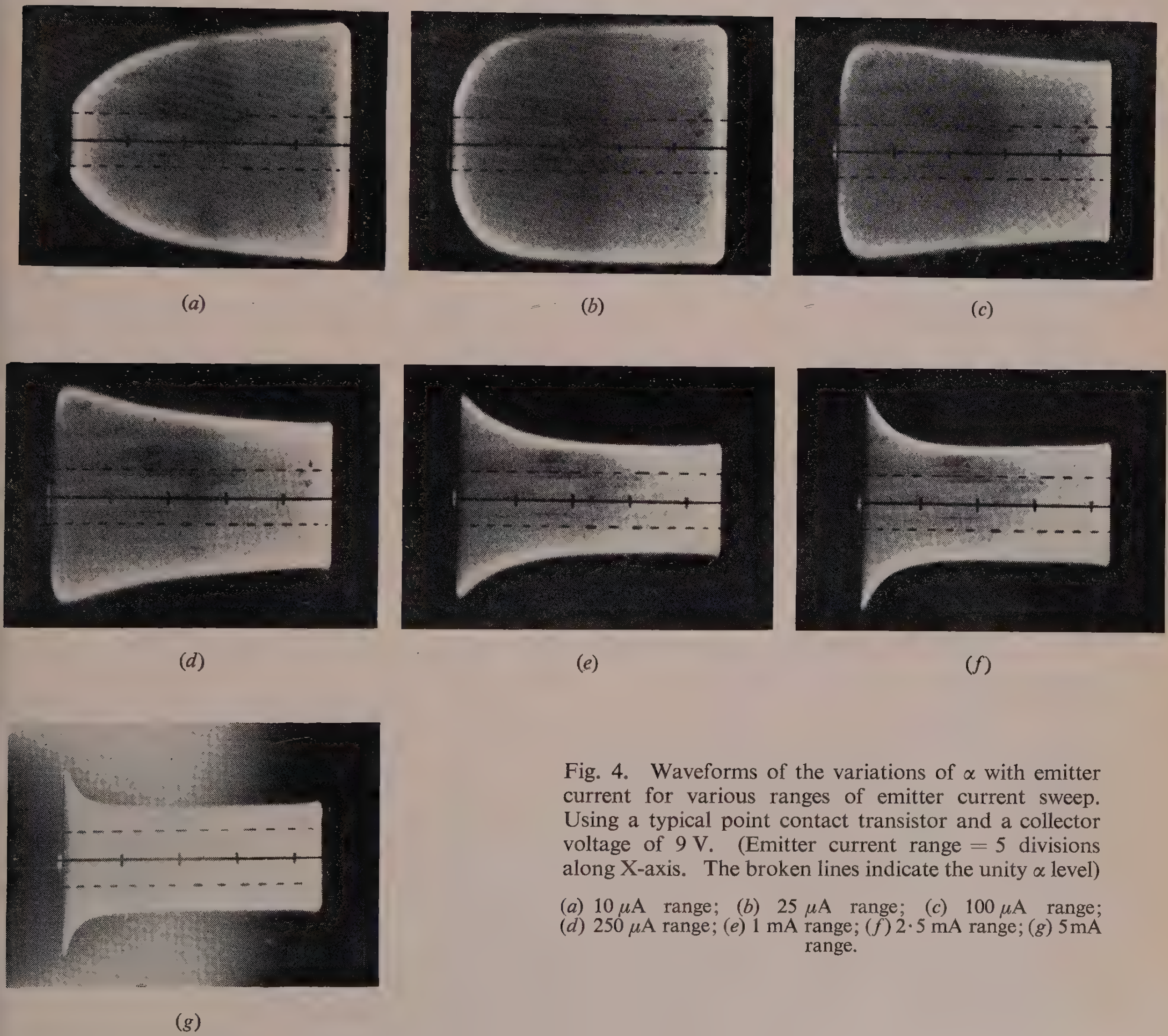


Fig. 2. Variation of α with emitter current (5 mA range) for a high frequency point contact transistor, showing the effect on the waveform of the collector output impedance becoming negative at $I_E = 2{\cdot}4$ mA



(*a*) (*b*) (*c*) (*d*) (*e*) (*f*) (*g*)

Fig. 4. Waveforms of the variations of α with emitter current for various ranges of emitter current sweep. Using a typical point contact transistor and a collector voltage of 9 V. (Emitter current range = 5 divisions along X-axis. The broken lines indicate the unity α level)

(*a*) 10 μA range; (*b*) 25 μA range; (*c*) 100 μA range; (*d*) 250 μA range; (*e*) 1 mA range; (*f*) 2·5 mA range; (*g*) 5 mA range.

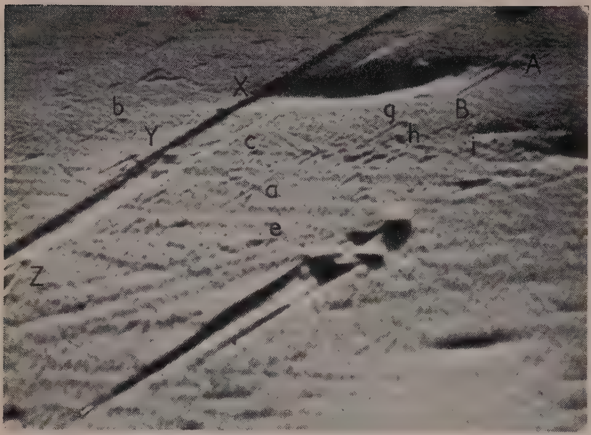


Fig. 4

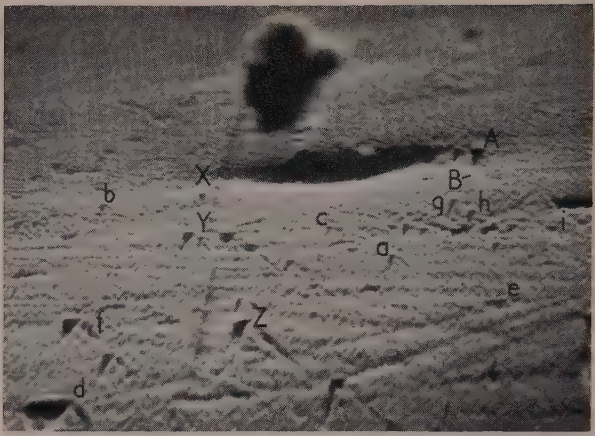


Fig. 5

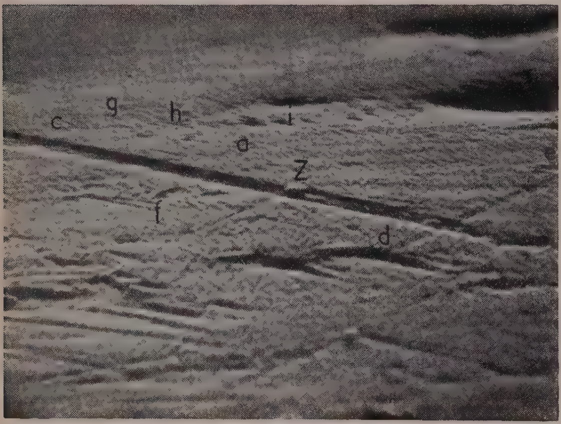


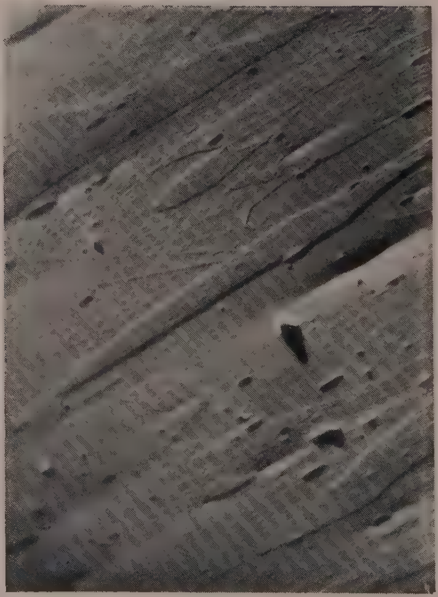
Fig. 6

Figs. 4, 5, 6. Reflexion electron micrograph of polished silver surface, in varying azimuth to the illuminating beam; corresponding points are lettered for identification (cf. text)

Magnification ×1400; $\theta_1 = 1°$; $\theta_2 = 4°$; $V = 60$ kV.

Fig. 7. Reflexion electron micrograph of Armco iron

Magnification ×1300; $\theta_2 = 8°$; $V = 60$ kV.



Certain errors which normally effect such diffraction patterns ue to distortion and rotation produced by the lenses, ncertainty in the specimen position and chromatic aberration, may be compensated by correctly choosing the lens parameters and the inter-lens distances.(10)

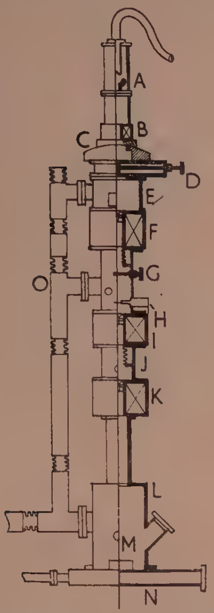


Fig. 1. Reflexion electron microscope (diagrammatic)

The four lenses are similarly constructed. The soft iron nner tube is made in two parts, turned together with the nd plates from the solid, and joined by a brass spacer oldered in position. The lens is completed by slipping an uter tube, also of soft iron, over the windings. It is bolted ard to the end plates in order to reduce the loss of magnetomotive force at the junctions, and the stray fields which are roduced there lie outside the Mumetal cylinders which shield he electron beam. Separate pole pieces which drop into apers in the lens bores are used in the objective and projector enses; the iron used was chosen for its homogeneity, low oercive force, and reasonably high permeability of 1500 at 0 000 oersteds. The pole pieces were polished but not arefully lapped since an astigmatism of 10 μ corresponds, or a semi-angle of illumination of 3×10^{-3} rad, to a disk f least confusion of radius 150 Å, a figure well below the imit imposed by chromatic aberration. The final design hosen for the objective pole piece was bore $D = 4$ mm, nd gap $S = 2{\cdot}4$ mm. When the lens excitation k^2 is 0·28 he calculated focal length is 6·2 mm and the chromatic berration constant 5·5 mm; the thickness of the upper pole f the pole piece is 2·5 mm so that the object plane lies pproximately 2·5 mm clear of the top surface. The choice f the other lens parameters was made to provide the desired nagnification range and to produce aberration-free diffraction atterns.(10,11)

Apertures. The electron beam is defined by a system of our apertures. To limit the angular spread of the imaging eam it is necessary to use a physical objective aperture since cattering in the specimen invalidates the procedure of efocusing (backing off) the condenser lens. The minimum seful objective aperture is fixed by the practical need to see he image in order to focus it, rather than by a theoretical alculation of the condition for optimum resolution 3×10^{-4} rad). When the electron gun is operated at naximum efficiency and the electron cross-over is focused y the condenser lens on to the specimen, it is possible to reduce the semi-angle of the imaging beam to $2\text{–}3 \times 10^{-3}$ rad. The semi-angle of the illuminating beam is limited by a 2 mm condenser aperture to 5×10^{-3} rad (with a smaller aperture the image brightness is reduced; it is not significantly increased by a larger aperture).

Two different objective apertures have been used during the work. In the first a ball joint is mounted in the base of the objective pole piece. The aperture is carried on a tube fixed to the ball so that it lies in the back focal plane of the lens, and it is centred by means of a tool which fits into the specimen stage. This system has the disadvantage that, as the specimen stage has to be occupied by a special tool, it is not possible to adjust the position of the aperture while observing a specimen. The second system also comprises essentially aperture, vertical carrying tube, and ball joint, but the tube now slides through a diametral hole drilled vertically through the ball, and projects down into the section *G* (Fig. 1) where it slides through a collar. The position of the aperture is set from outside the microscope by three rotary controls; a fork which engages with two pegs in the brass tube governs the vertical position, while two 40 turns/in. screws govern the horizontal. These are used to move the collar, and the motion transmitted to the aperture is demagnified 3 : 1 by the tube acting as a lever pivoted at the ball.

During diffraction studies an aperture *H* may be used to limit the area of the object contributing to the diffraction pattern. The plane of *H* is conjugate with the object and an aperture of 100 μ corresponds to a 5 μ region of the specimen.

Finally a group of three apertures, 1·5 mm in diameter, is inserted in the projector pole piece in order to improve image contrast. The field of view is not seriously limited even at low magnification (×500) and, since only $\frac{1}{9}$th of the projector bore can be filled by imaging rays, the image distortion produced by the projector is unimportant.

Alinements. The electron gun alinements, designed so that a symmetrical electron beam passing through the centre of the condenser lens may be obtained, have been described; the other adjustments are a tilt and traverse of the illumination system and traverses of the objective and intermediate lenses. Fig. 2 shows the combined illumination tilt and traverse mechanism. It is essentially simple and comprises

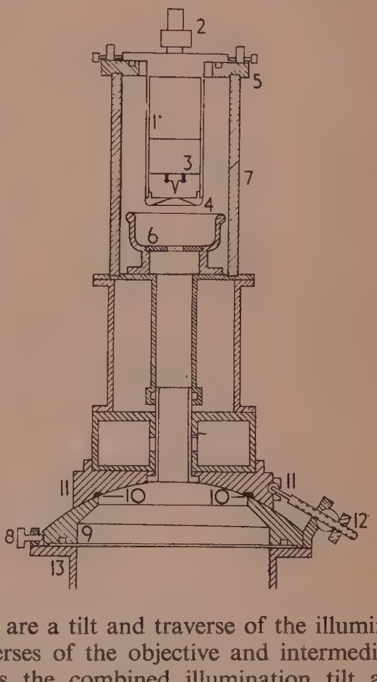


Fig. 2. Electron gun and condenser lens, with tilt and traverse mechanisms (section)

three brass blocks (11, 9, 13). The blocks (9) and (11) have mating surfaces which are spherical and centred on the object, and the blocks (9) and (13) mating surfaces which are plane. Friction is reduced by carrying blocks (9) and (11) on graphite pads (as at 10) of such a thickness that the compression of the rubber O-rings used to seal the vacuum is 0·25 mm. Four 26 turns/in. screws (12) are used to tilt the block (11); the traversing screws are oriented at 45° to the plane of the diagram and are not shown. Both tilt and traverse motions may be made smoothly with the microscope at low pressure and while observing the image; the maximum angle of tilt is 10°.

Specimen holder. A simple specimen stage in which the specimen holder and the door of the object chamber E form one unit is shown in Fig. 3. The cylindrical specimen, 9 × 9 mm, fits into a tube (1) and is clamped by a locking screw. Two pegs soldered to the tube are held in slots in the two plates (2) which are rigidly fixed to either side of the hollow shaft (5), and by rotating the knob (3) the shaft (4) is driven forward and the specimen is tilted about the axis formed by the pegs. The counter thrust is provided by the spring (8). The specimen may be traversed horizontally in one direction by rotating the nut (6), which is held captive to the shaft (5) by two keys (7), and in the other direction by rotating the shaft. Although the latter motion is strictly a rotation about the shaft axis it is approximately linear for small angles of rotation.

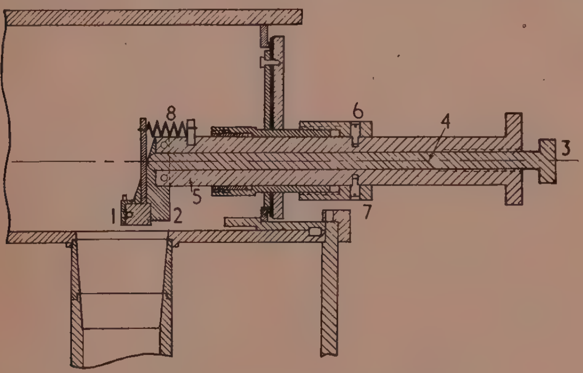


Fig. 3. Specimen stage (section)

A more complicated specimen stage and specimen furnace has also been used but since it is to be described elsewhere[12] it is sufficient to mention the degrees of freedom regarded as desirable.

The two horizontal motions are essential if the whole of a specimen is to be examined; the vertical motion is not required except that it is profitable to preset the specimen so that it just clears the pole piece in order to reduce the focal length, and thus the chromatic aberration constant, of the lens as far as possible. As different horizontal bands of the specimen are imaged the effective object distance varies and the objective lens has to be refocused; the magnification changes, and thus any magnification calibration of the microscope has to be made in terms of objective current. The effect of the glancing angle of reflexion θ_2 is to control the foreshortening of the image. It is reported by Fert and Saporte[4] that image sharpness (or resolution referred to the Gaussian image plane) decreases as θ_2 is increased, but since the effect is not marked most workers have preferred to set θ_2 between 4 and 10° in order to reduce the foreshortening. It is not essential to be able to vary this angle during observation; a preset control is adequate. The glancing angle of incidence θ_1 is, however, critical, and mu be continuously variable. It controls image contrast and i optimum value, which is related to surface roughness, ca be gauged only by viewing the image—too large a valu results in insufficient contrast; at too small an angle th overlong shadows cast by asperities and the intense scatterin from the illuminated peaks produce a confused picture. may be usefully varied between 4° and almost 0°, smoothe surfaces requiring smaller values; and it can be controlle by tilting either the illuminating system or the object. Th last parameter of importance is the angle of azimuth of th specimen ϕ. By rotating the specimen surface in its ow plane one may obtain a series of pictures each giving a nea profile view of the surface, and a rotation of 15° is sufficie to change completely the proportions of the image (se Figs. 4, 5 and 6 in which corresponding points are lettere similarly). The figures also show how ϕ controls imag contrast; thus the visibility of the long trough XYZ minimized when it lies parallel to the electron beam directio as in Fig. 5. The problem of specimen stage design is, there fore, that of providing two linear motions and a fine rotatio in azimuth. If there is no fine control of the tilt of th illumination system a continuously variable specimen tilt essential; otherwise a preset choice of this angle suffices.

The other details of the microscope are conventional. simple transmission stage is provided, the centre of which removed during reflexion work. The camera N (Fig. takes three 9 × 6 cm plates which may be exposed in halve or film; an air lock facilitates the rapid change of plates. Th vacuum system comprises a rotary oil pump, a 10 l. pumpin reservoir, and a mercury diffusion pump, together with th valves and bypass line necessary to allow primary evacuatio of the camera or of the whole microscope while keeping th diffusion pump at high vacuum. There is no specimen a lock, but while changing specimens the electron gun is seale off by closing the valve D (Fig. 1). A Pirani gauge is installe in the high vacuum system for indicating critical workin pressure and for leak testing.

The three imaging lenses of the microscope draw a max mum total current of 1 A which is supplied from a 24 accumulator bank; the condenser lens is fed separately fro three 2 V accumulators. The high voltage is variable fro 30 to 85 kV. An alternating voltage, 15 kV peak to peal generated by an 11 kc/s oscillator and ferrous cored h. transformer, is injected into the bottom of a voltage doublin stack, and the output is smoothed and stabilized by tw feed-back loops (cf. Strojnik[13]).

IMAGE QUALITY

As well as the three terms C_c, α and $\Delta V/V$, which ent into the expression for resolving power, a number of othe factors may influence the information obtainable fro reflexion micrographs; the choice of θ_1, θ_2 and ϕ has bee already mentioned. The effect of specimen contaminatio caused by the electron beam is shown clearly in Figs. 4 and AB is the contamination shadow formed by the particle when the angle of incidence θ_1 was smaller than that use for taking the photograph. While it is possible to avoi such spurious details by working first at the larger and the at the smaller angles, it is not possible to avoid producing series of radiating shadows as the angle ϕ is change (Swallow tails are visible behind asperities such as a, b, c, Fig. 5.) A pattern of such shadows reduces resolution an makes interpretation of the photographs difficult, and obtain full information from a series of pictures taken at different angles of azimuth it is essential to prevent the formation of specimen contamination. The most satisfactory method is that of ion bombardment developed by Fert.(14)

The centring of an objective aperture placed in the back focal plane of the objective lens must be done accurately. A slight displacement of the aperture effectively perpendicular to the plane of incidence of the electrons has little effect, but a displacement in that plane (as the aperture is moved the foreshortening in the image varies) is critical; a misalinement of $\frac{1}{4}$ diameter of a 75 μ aperture is sufficient to impair resolution noticeably.

Finally the lateral extent of the field that is in sharp focus may be limited by chromatic changes of magnification and rotation. The rotational error may be reduced sufficiently by choosing opposite senses of current rotation in the objective and projector lenses; a compensation of the magnification aberration may be made in a three-lens instrument if the focal length of the intermediate lens is correctly chosen. If the magnification of a three-lens system is calculated using thin lens formulae one may show that the magnification is invariant with respect to voltage at the approximate condition

$$2d_1d_2/f_2 = d_1 + d_2$$

and that the corresponding magnification is $(d_1 + d_2) \times M_3/2a$, where d_1 and d_2 are respectively the distance between the first and second pairs of imaging lenses, f_2 the focal length of the intermediate lens, M_3 the magnification of the projector lens and a the specimen distance.

The microscope has been used to examine a number of metal specimens (an example of Armco iron is shown in Fig. 7) and some observations have been made of surfaces at high temperature.(12) Resolutions of the order of 500 Å have been obtained at normal temperatures.

ACKNOWLEDGEMENTS

The authors wish to acknowledge valuable discussions with Mr. M. E. Haine and Dr. J. W. Menter, the receipt of specimens from Mr. E. Hyam and Dr. J. Dyson and the services of Mr. A. Strojnik in constructing the h.t. set. The work has been supported by the British Iron and Steel Research Association, and by a BISRA bursary granted to one of us (D.J.).

REFERENCES

(1) Ruska, E., and Müller, H. O. *Z. Phys.*, **116**, p. 366 (1940).
(2) von Borries, B. *Z. Phys.*, **116**, p. 370 (1940).
(3) Kushnir, U. M., Biberman, L. M., and Levkin, N. P. *Izv. Akad. Nauk, SSSR, Ser. Fiz.*, **15**, p. 306 (1951).
(4) Fert, C., and Saporte, R. *C.R. Acad. Sci.* [*Paris*], **235**, p. 1490 (1952).
(5) Menter, J. W. *J. Inst. Metals*, **81**, p. 163 (1952).
(6) Haine, M. E., and Hirst, W. *Brit. J. Appl. Phys.*, **4**, p. 239 (1953).
(7) Cosslett, V. E., and Jones, D. Electron Microscopy Conference, Bristol, 1952. For summary, see *Nature* [*London*], **170**, p. 861 (1952).
(8) McMullan, D. *Proc. Instn Elect. Engrs*, **100**, p. 245 (1953).
(9) Möllenstedt, G., and Duker, H. *Optik*, **10**, p. 192 (1953).
(10) Cosslett, V. E., and Jones, D. *Comptes Rendues du Premier Congrès International de Microscopie Electronique, Paris*, 1950 (Paris: *Revue d'Optique*, 1953).
(11) Jones, D. Thesis, University of Cambridge (1953).
(12) Jones, D. *Proc. Int. Conf. Elect. Microscopy, London*, 1954. To be published.
(13) Strojnik, A. *Elektrotechnical Review* [*Ljubljana*], No. 5/6, p. 131 (1953).
(14) Fert, C. *C.R. Acad. Sci.* [*Paris*], **238**, p. 333 (1954).

A Pirani gauge circuit

By C. N. W. Litting, Ph.D., A.M.I.E.E., A.Inst.P., Electrical Engineering Laboratories, University of Manchester

[*Paper received* 26 *August*, 1954]

A detector circuit employing a germanium rectifier is used in conjunction with a direct-reading constant-temperature type of Pirani gauge. By this means a near linear calibration is obtained.

The gauge is of the direct-reading constant-temperature type.(1, 2) It has been designed with a view to maintaining the advantages of that type of gauge whilst obtaining a near linear calibration. The Pirani element is a 60 W 110 V coiled tungsten lamp filament having a cold resistance of about 12 Ω and stretched to a length of 4 cm.

The design of the feedback amplifier is not critical; the circuit used is shown in Fig. 1, and was arranged to have a resonance at approximately 1 kc/s. Provided the gain of the amplifier is high and the feedback is in the right sense, the bridge containing the Pirani element will be kept close to balance and the voltage (V) may be taken as a measure of the pressure. In fact if the voltage across the bridge is plotted as a function of pressure, a section of a parabola of the form

$$p = A(V^2 - V_0^2)$$

(where A and V_0 are constants) is obtained.

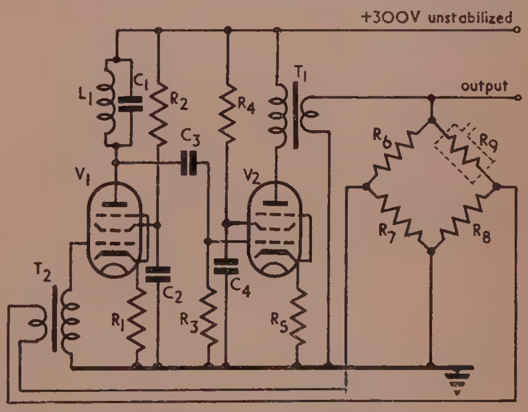


Fig. 1. The feedback amplifier

$R_1 = 220\ \Omega$
$R_2 = 18\ \text{k}\Omega$
$R_3 = 470\ \text{k}\Omega$
$R_4 = 18\ \text{k}\Omega$
$R_5 = 220\ \Omega$
$R_6 = 2\ \Omega$
$R_7 = 20\ \Omega$

$R_8 = 300\ \Omega$
$R_9 =$ Pirani element

$L_1 = 300$ mH

$T_1 = 82 : 1$ (step down)
$T_2 = 1 : 306$ (step up)

$C_1, C_2 = 0{\cdot}1\ \mu\text{F}$
$C_3 = 0{\cdot}01\ \mu\text{F}$
$C_4 = 0{\cdot}1\ \mu\text{F}$

$V_1, V_2 =$ EF50

In order to obtain a linear characteristic, use is made of the nearly parabolic characteristic of a germanium rectifier. A simple circuit for this purpose is shown in Fig. 2(a) whilst typical calibrations for air and hydrogen are shown in Fig. 3. This circuit cannot be expected to give a perfectly linear calibration, for even with an ideal rectifier characteristic and a measuring device of zero impedance the output would be proportional to $(V - V_0)^2$ and not $(V^2 - V_0^2)$. It will be observed, however, that the calibration shown in Fig. 3 is nearly linear. Fig. 4 summarizes the results obtained when using rectifiers having vastly different characteristics, and shows that the calibration of the gauge is hardly influenced by the parameters of the rectifier.

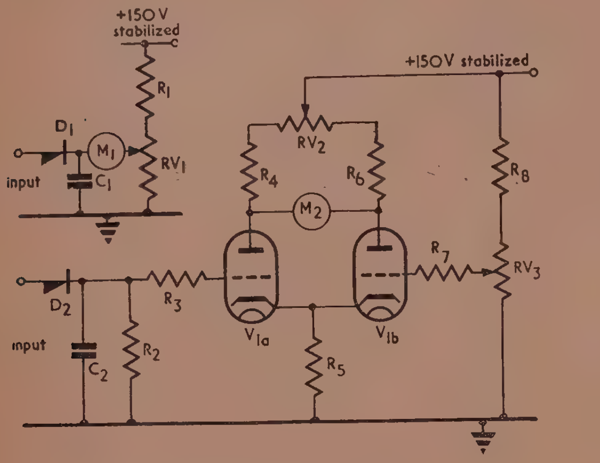


Fig. 2. Detector circuits

R_1 = 100 kΩ
R_2 = 120 Ω (or 3·3 kΩ)
R_3 = 2·2 MΩ
R_4 = 10 kΩ
R_5 = 2·2 kΩ
R_6 = 10 kΩ
R_7 = 2·2 MΩ
R_8 = 100 kΩ
RV_1 = 5 kΩ
RV_2 = 7·5 kΩ
RV_3 = 5 kΩ
C_1, C_2 = 250 μF
D_1, D_2 = WG7B
M_1 = 250 μA, full-scale deflexion 1·7 kΩ } AVO Model 8
M_2 = 2·5 V, full-scale deflexion 50 kΩ } AVO Model 8
V_1 = 6SN7

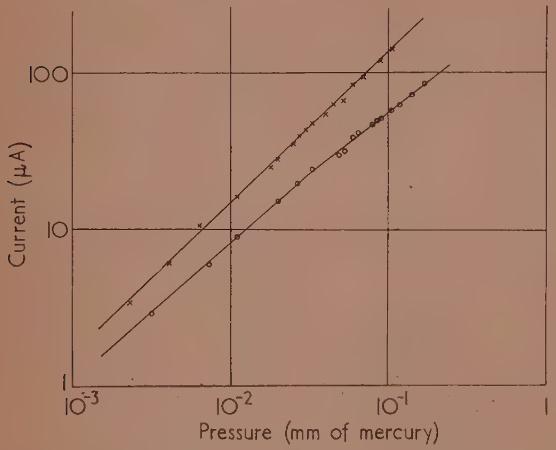


Fig. 3. Calibration of gauge employing first detector circuit

○ = air; × = hydrogen.

A circuit employed to obtain a more linear calibration is shown in Fig. 2(*b*) whilst Fig. 5 shows calibrations obtained with this circuit. The linearity of the calibration is improved, as would be expected, for the circuit should give an output proportional to $V^2 - V_0^2$ if the rectifier has a parabolic characteristic. As indicated in Fig. 5 the calibration is now effected by the characteristic of the rectifier used and therefore every model would require individual calibration. In order to reduce this dependence on the characteristic of the rectifier the resistance R_2 [Fig. 2(*b*)] can be increased but this results in some loss in linearity.

The gauge is remarkably free from zero drift when either circuit is used. In fact once the zero is set for a particular filament it very rarely requires adjustment.

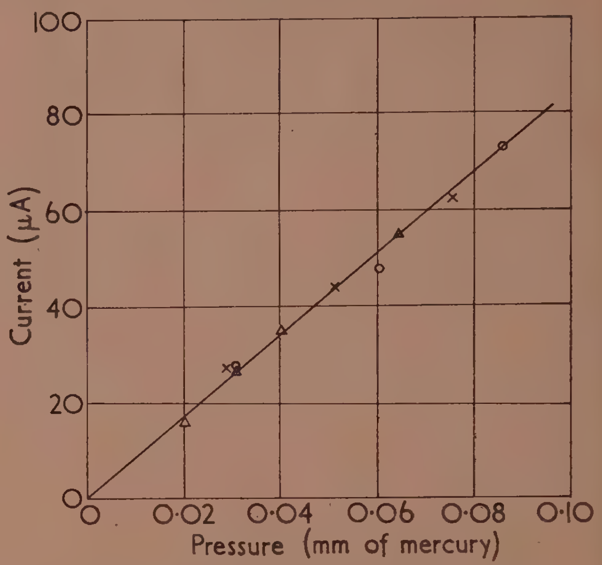


Fig. 4. Effect of rectifier characteristics

○ = forward resistance 420 Ω; back resistance 62 kΩ
× = forward resistance 600 Ω; back resistance 130 kΩ
△ = forward resistance 550 Ω; back resistance 1·5 MΩ

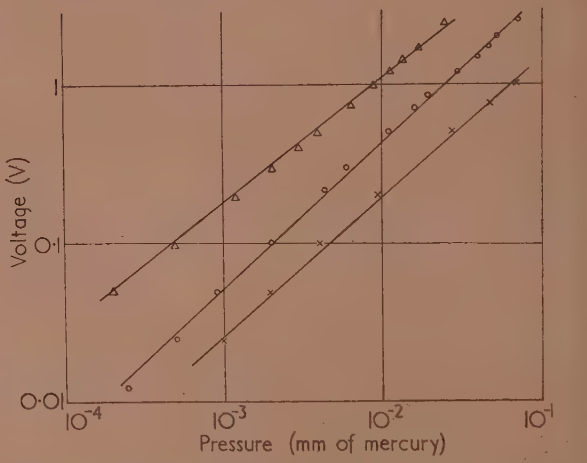


Fig. 5. Calibration of gauge employing second detector circuit

○ = R_2 120 Ω; forward resistance 550 Ω; back resistance 1·6 MΩ
× = R_2 120 Ω; forward resistance 420 Ω; back resistance 62 kΩ
△ = R_2 33 kΩ; forward resistance 420 Ω; back resistance 62 kΩ

ACKNOWLEDGEMENT

The author wishes to acknowledge the help of Mr. D. Orme who carried out some of the measurements described in this paper.

REFERENCES

(1) Spangenberg, K. R. *Vacuum Tubes*, p. 768 (New York: McGraw-Hill Book Co. Inc., 1948).
(2) Von Dardel, G. *J. Sci. Instrum.*, **30**, p. 114 (1953).

A dielectric heating and test unit for the study of sand properties at elevated temperatures

By R. Rew and R. G. Godding, The British Cast Iron Research Association, Alvechurch, Birmingham

[*Paper first received* 30 *September, and in final form* 18 *November*, 1954]

To obtain rapid and uniform heating of sand specimens, a dielectric heater operating at 100 Mc/s has been built. This is used in conjunction with a mechanical testing apparatus that records the stress/strain relation on a photographic plate and also gives an indication of the brittleness of fracture of the specimen.

To evaluate the suitability of sands for the production of foundry moulds it is necessary to obtain data on the stress/strain relationship and expansion of sand compacts at elevated temperatures.

Due to the low thermal conductivity of sand, test specimens heated in normal resistance furnaces attain uniform temperature very slowly. During this time the organic materials decompose, and the mechanical properties of the sand are changed to such an extent that tests on a specimen heated in this manner are of doubtful practical value. The most likely method of obtaining rapid and uniform heating throughout the specimen appeared to be by dielectric heating. This paper describes the construction of a very high frequency dielectric heater built to work in conjunction with an apparatus that measures the stress/strain relationship of a 2 × 2 in. cylindrical sand test-piece, at all loads up to and beyond breaking point. A schematic diagram of the apparatus is shown in Fig. 1.

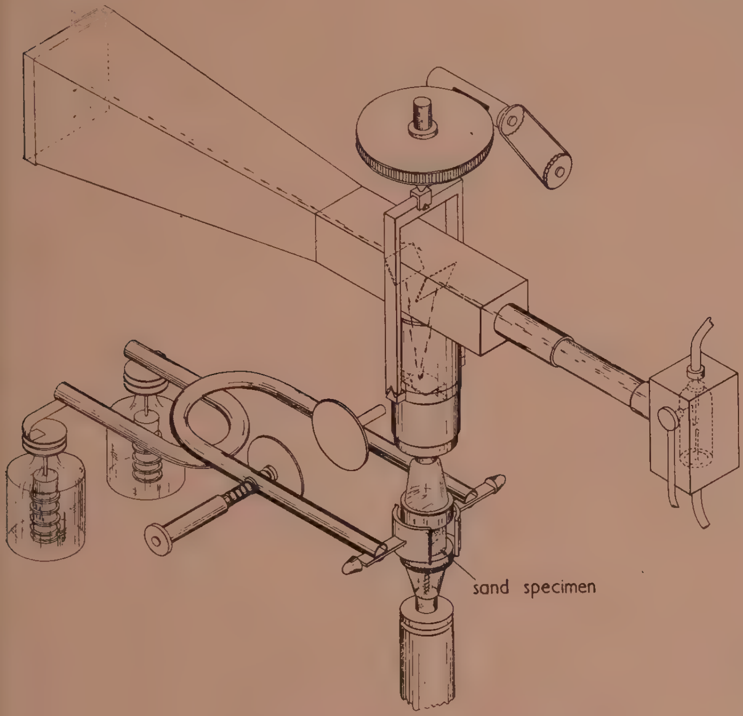


Fig. 1. Schematic diagram of the apparatus

POWER AND FREQUENCY CONSIDERATIONS

If the loss factor of pure quartz is considered, the power and extremely high frequency required to give the necessary rate of heating in one minute are impracticable. The type of sand used in the foundry, however, consists of quartz with up to 30% of impurities in the form of clays, felspars, iron oxides, and coal dust or pitch. Attempts to heat sands of this nature in conventional dielectric heaters operating in the 10–20 Mc/s region had previously met with little success. The results obtained on a number of typical foundry sands indicated that loss factors in the range of 0·2 to 0·7 could be expected at 100 Mc/s.

The power requirements necessary to raise a standard 2 × 2 in. diameter test specimen to 1000° C in one minute indicated a thermal input of 2·8 kW to the specimen. The calculation of the power required to supply radiation, conduction and convection losses from the specimen would be an extremely complicated process involving many assumptions. A figure of 50% of the thermal power input to the specimen to supply these losses was, therefore, assumed, and to be added to this was the power required to bring about changes of state in the quartz content of the specimen and supply resistance and radiation losses in the tank and load circuits of the oscillator.

A summing up of the total power necessary to heat the specimen at the desired rate indicated that an oscillator with a power output of some 4–5 kW would be required.

DESIGN OF THE OSCILLATOR

From the somewhat limited number of valves available, a pair of all-glass very high frequency triodes were selected, capable of operation at full ratings at 100 Mc/s with forced air cooling. The power output possible from these valves was only about 60% of that considered necessary, though it was thought that, due to the short duty cycle employed, it might be possible to exceed the ratings for short periods if necessary.

At very high frequencies, push-pull operation leads to better circuit symmetry and larger tank circuits, as the valve capacities appear in series across these circuits. The radio-frequency voltage across the anode tank circuit is also double that obtained for a single valve or two valves operated in parallel. This is an advantage where, as in the present instance, a high tank circuit voltage is desired. It was also anticipated that the load would be symmetrically placed with respect to the load plates, further helping to preserve the balance in a push-pull system.

The oscillator tank circuit consists of a shortened quarter-wavelength parallel line resonated at 100 Mc/s with the valves at the high potential end. The load circuit line is of similar construction, tuned by the load and its associated plates at the high potential end in conjunction with a variable two-plate circular capacitor about halfway along the line. The tank and load circuit lines are arranged to have a variable amount of inductive coupling between their respective low potential ends. This arrangement facilitates operation of the equipment, the lines being retuned during actual operation to compensate for varying load changes.

Some early difficulties were encountered with breakdown of insulators at the high potential end of the load line, and the original method of plate adjustment through the sides of the heating chamber was eventually discarded in favour of plates mounted directly on the end of the load line. The line is supported by four long-path polytetrafluorethylene insulators situated away from the high potential end.

The specimen is supported between the loading heads by two hollow bell-type Pyrex insulators with their open ends facing the sand specimen. Between these open ends and the specimen are interposed two fused silica disks, 2·5 in. diameter and 0·5 in. thick. This arrangement is convenient, since it is possible to remove the silica disks for cleaning purposes, and the lower bell-type insulator is a convenient method of introducing a thermocouple for temperature measurement during actual heating, as mentioned later in the paper.

CONSTRUCTION OF THE OSCILLATOR

The oscillator high-voltage power supply and control gear, together with the electronic flash unit, are mounted in a mobile floor cabinet. The front panel of this cabinet is virtually the control desk for the whole apparatus. The power output of the oscillator, the motor driving the loading-head screw-jack and the flash lamp are controlled from this panel.

The oscillator power unit is of conventional design, employing four half-wave mercury vapour rectifying valves in a bridge circuit. The output from the high-voltage power unit is controlled by a Variac feeding the primary of the high-voltage transformer.

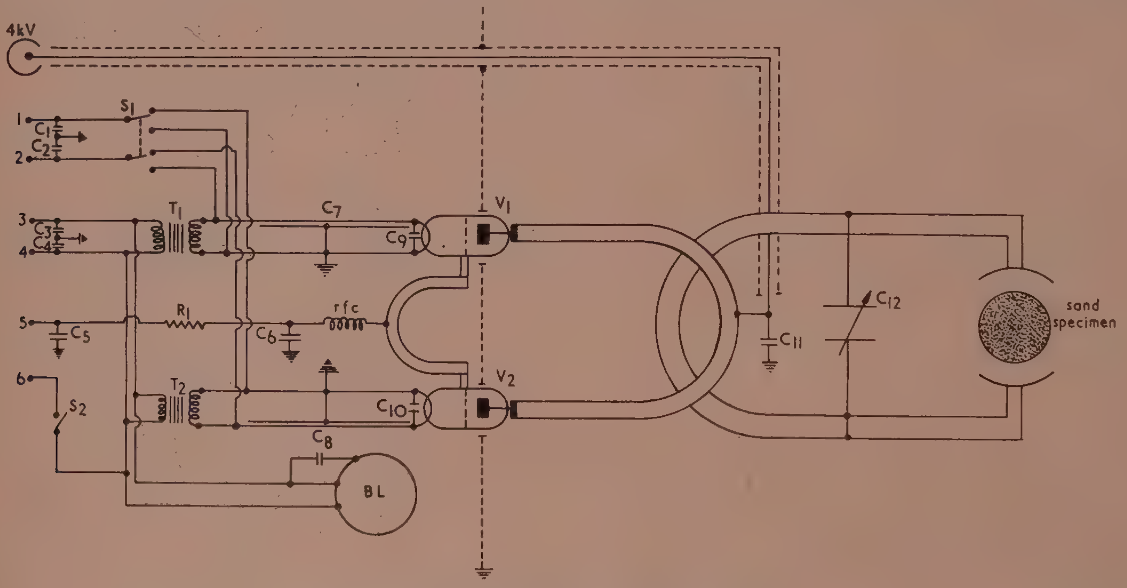


Fig. 2. Circuit diagram of oscillator unit

R_1 = 1600 Ω, 100 W, w.w.
C_1–C_5 = 0·001 μF, 350 V, mica
C_6 = 0·00015 μF, 500 V, mica
C_7, C_8 = copper-strip capacitor, 0·0004 μF, mica
C_9, C_{10} = 0·01 μF, 750 V
C_{11} = 0·001 μF, 6 kV, mica
C_{12} = two-plate capacitor
V_1, V_2 = TY4–500 (Mullard)
S_1 = double-pole changeover switch
S_2 = microswitch
T_1, T_2 = 10 V, 10 A
BL = axial flow blower, 275 ft³/min
R.F.C. = radio-frequency choke

The oscillator, Fig. 2, is built into a copper screening box, 14 in. square × 23 in. high. This box is mounted on two guide rails fixed to the base of the heating chamber, and is bonded to the sheet-copper screening of the heating chamber by copper mesh gauze. The heating chamber is fitted with a hinged door at the end remote from the oscillator to facilitate access to the loading heads and specimen plates. The oscillator valves are mounted side by side on a platform in the screened box. They operate as a push-pull grounded cathode oscillator with a quarter-wavelength line in their anode circuits. This line is made from 1⅛ in. diameter silver-plated copper tubing and is supported only at the low potential end by a rigid bar going to one terminal of the mica bypass capacitor, C_{11}. No tuning condenser is incorporated, the line length being such that the desired frequency of 100 Mc/s is obtained. It was found unnecessary to arrange for adjustment of the grid line length, a flat copper strap joining the grid pins of the two valves proving to be of suitable inductance to provide the feedback necessary for correct grid current at full input under loaded conditions.

The filament transformers and axial air blower for valve cooling are mounted in the base of the box. The cooling air is arranged to blow directly on the base of each valve and is also led through two Bakelite tubes to provide an air flow directly on to the anode connectors of the valves. One side of each valve filament is returned to the filament transformer *via* the valve platform, the other side being by-passed to the platform by copper strip capacitors, C_7 and C_8, using mica sheet insulation.

The heating chamber load circuit line is also made of 1⅛ in. diameter copper tubing, and is positioned so that its low potential end is immediately above that of the oscillator line. Inductive coupling adjustment is made by sliding the oscillator along the guide rails, the small movement necessary being permitted by the copper-gauze screening. A knob operating a coarse-threaded adjustment on one of the load line tuning capacitor plates projects through the side of the heating chamber.

The specimen plates operate with an air gap of about 0·5 in. with respect to the sand test-piece, the latter being surrounded by a close-fitting silica heat shield. This shield is in three segments to allow the specimen to deform during the mechanical test. The specimen plates are polythene-coated in order that the maximum available voltage may be used without electrical breakdown. The plates and the load ne are water-cooled, the water inlet and outlet being at the w potential end of the line.

Throughout, in the construction of the oscillator and eparate load circuit, every endeavour was made to maintain hysical and electrical symmetry.

MEASUREMENT OF SAND TEMPERATURE

It was necessary to measure the temperature of the sand pecimen continuously during heating. A hole was drilled rough the bottom loading head support, and a thermoouple was introduced axially into the centre of the specimen rough the lower bell type insulator and a small hole in the ottom silica disk. A small spring in the bell-type insulator erves to maintain the thermocouple in intimate contact with ne specimen. The thermocouple leads are passed through a adio-frequency filter network before being fed to the measurng instrument. A millivoltmeter was originally employed, ut it has also been found possible to use electronic high-speed ecorders without any apparent interference from radio-equency currents.

THE TESTING MACHINE

The stress/strain curves are obtained from an apparatus hat traces the load deformation directly on to a photographic late. A schematic diagram of the principal parts of the esting machine is shown in Fig. 3. The specimen *S* is placed n a silica disk which rests on the open end of the lower bell-ype insulator, which is supported by a rigid steel column. he latter is directly beneath the test head *H*, and the load s transmitted to the specimen *via* the upper bell-type insulator nd silica disk. The load is applied at *FF* by means of a ynchronous motor-driven screw-jack and is transmitted to ne test head *H* *via* a knife-edge and a surface-ground alibrated spring-steel beam *B*.

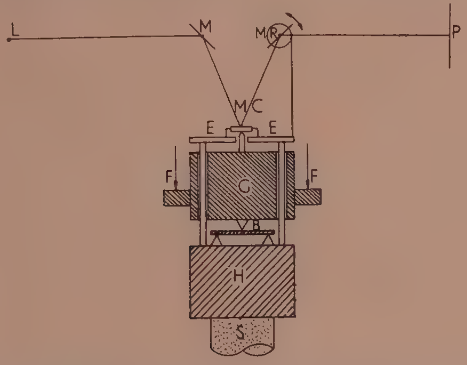


Fig. 3. Schematic diagram of the principal parts of the recording apparatus through which the load is applied

A mirror carriage *E* is also attached to the test head *H*, ne mirror being mounted on pin-point bearings and capable f being rotated by the movement of *G* relative to the carriage . The axis of rotation is horizontally on a plane with the aper. The supporting rods for *E* pass right through the lock *G*, and around these rods are the springs that counteralance the weight of *H* and the mirror carriage *E*. The two ylindrical blocks *G* and *H* are alined by being placed in a ube. The block *G* is rigidly fixed within the tube and the est head *H* is a good sliding fit.

When a load is applied at *FF*, the beam *B* bends and this auses the mirror *MC* to tilt in proportion to the load applied. f under this stress the sand specimen deforms, the test head will move downwards, and this movement is transformed o a rotary motion of the mirror *MR* by means of a rack and pinion linkage. The movement of *H* will also relax the spring *B* and thereby automatically reduce the load on the specimen. For each 0·001 in. deformation of the specimen, there is a stress relaxation of 40 lb if the system is considered in a static state.

To enable a record of these movements to be made, a beam of light from a lamp at *L* travels to the fixed mirror *M* and is deflected downwards on to the mirror *MC*. As this mirror tilts, the light beam is deflected in proportion to the load. The beam then falls on the mirror *MR* and, since this mirror rotates in proportion to the deformation of the specimen, the light beam is also deflected in proportion to the deformation of the sand specimen.

The two deflexions given to the light beam are in planes at an angle of 90° to each other, and, therefore, at point *P* a stress/strain curve is traced by the light. This tracing is recorded on a photographic plate. To enable the rate of strain to be read from the trace, the lamp, a Xenon-filled flash tube, is flashed at 300, 600 or 1000 times/min.

RESULTS

Completely uniform heating throughout the sand test-piece is not obtained, owing to the radiation and conduction losses from the sides and ends of the specimen. The temperature distribution has not been measured, but, from the results obtained on the expansion tests, the α to β quartz inversion at 573° C would not have been so clearly defined had irregular heating of the specimen taken place. Fig. 4 shows expansion curves obtained by radio-frequency heating compared with the curve obtained from a single crystal of pure quartz.*

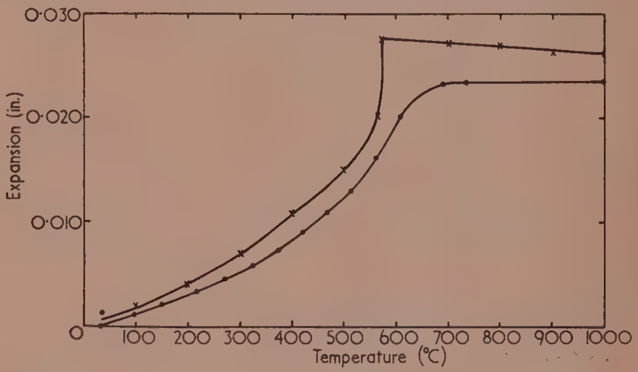


Fig. 4. Expansion curve of pure quartz compared with that obtained on a compacted sand test-piece

× = expansion curve. Pure quartz (after Sosman).
● = expansion curve. Sand: Erith + 5% bentonite. Dielectrically heated.

No difficulty is experienced in raising the temperature of the specimen to 1000° C. The time taken to reach this temperature depends upon the loss factor of the sand being heated and is of the order of two to three minutes. A dielectric change in the quartz content of the sand occurs during heating, resulting in a higher loss factor, after which it is relatively easy to get extremely rapid heating to temperatures in excess of the fusion point of the specimen if necessary.

ACKNOWLEDGEMENTS

The authors are indebted to the Director and Council of the British Cast Iron Research Association for permission to publish this paper.

---

* Sosman, R. B. *The Properties of Silica*, p. 382 (New York: Chemical Catalog Co. Inc., 1927).

An apparatus for measuring the elastic properties of gels

By L. J. Hastewell, Ph.D., A.Inst.P., and R. Roscoe, Ph.D., A.Inst.P., Physics Department, King's College, Newcastle upon Tyne

[*Paper first received* 26 *October, and in final form* 6 *December*, 1954]

A simple apparatus devised by McDowell and Usher for the demonstration of elastic properties in colloidal suspensions can be adapted to give numerical results. It consists essentially of a float which is placed coaxially in a cylindrical vessel containing the suspension. A pair of vanes are carried by a spindle attached to the float so that the latter can be set in rotation by directing jets of air on to the vanes. In the case of gels, the subsequent rotation of the float is usually oscillatory, and the dynamic rigidity and dynamic viscosity can be calculated from the frequency and decrement of the oscillations. The apparatus has to be calibrated with a liquid of known viscosity having the same density as the gel.

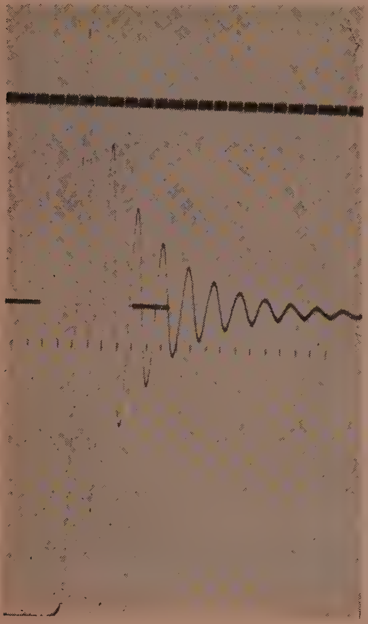


Fig. 1. A record obtained with a suspension of bentonite in water. (In this case the stress has exceeded the yield value)

When a float is placed in a Newtonian liquid and set in rotation by the application of an impulsive torque, it continues to rotate in the same sense with gradually decreasing angular velocity. In an elasto-viscous material, however, the initial rotation is usually followed by a recoil in the opposite sense. A single reversal of the direction of rotation is all that is observed in some cases, but in others the float proceeds to execute well-marked damped oscillations (Fig. 1). As pointed out by McDowell and Usher,(1) the presence of any recoil is a sensitive indication of elastic properties.

Observations on the rotation can also establish whether the elasto-viscous material is a liquid or a solid, since in the latter case the float returns finally to its original orientation provided that the initial impulse is not so large that the stress exceeds the yield value. Colloidal suspensions which behave as solids, here referred to as "gels," show fairly well defined yield points (Fig. 2) below which they exhibit linear stress-strain characteristics with pronounced hysteresis. The motion of the float is usually oscillatory with gels, while a single recoil is all that is obtained with most true elastic liquids. Numerical data can be extracted only from records of the oscillatory type of motion, so the apparatus will only be considered further in its application to gels.

Somewhat similar methods for the determination of elasto-viscous properties have been proposed from time to time, but in all of these a heavy cylinder suspended by a torsio wire has been used instead of a float. In some cases th calculation of the results has been vitiated by neglect of th important influence of the inertia of the elasto-viscou material, although approximate methods of taking this int account have been suggested by Goldberg and Sandvik.(2 Also Oldroyd,(3) by using the exact theory for the motio between coaxial cylindrical surfaces of infinite length, ha obtained a theoretical basis for an apparatus described b Oldroyd, Strawbridge and Toms(4) in which inertia is full taken into account. Since no allowance is made for the end effect in that theory, long cylinders with small clearance ar used in the apparatus and the small end-effect is eliminate by making observations with different depths of material.

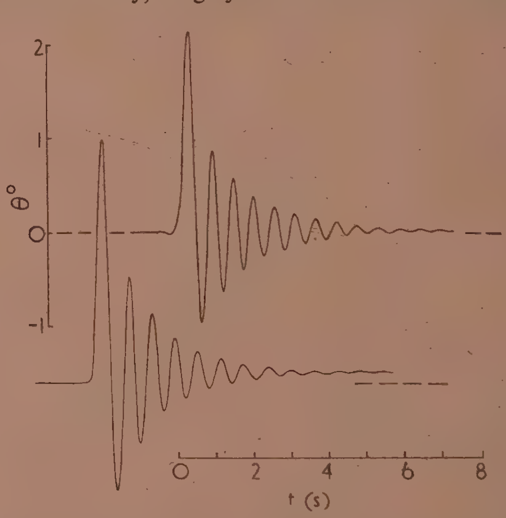


Fig. 2. Tracings from records obtained with a bentonite suspension (2·61 g/100 cm^3) containing potassium chromate (0·09 g/100 cm^3). The lower trace was obtained with a slightly larger impulse on the float and the yield stress has just been exceeded

The theoretical treatment of the rotation of an embedde body becomes simplified when there is no torsion wire, an a general treatment for a float and container of arbitrary form is given here in a later section. It is shown that, for gels o a given density, the oscillations are determined by the elasto-viscous properties and a single apparatus constant which may be obtained by calibration with a Newtonian liquid of know viscosity. As the theory applies to a float and container o arbitrary form, no question of end effects arises and larg clearances can be used. The apparatus is thus much easie to construct than that used by Oldroyd, Strawbridge an oms. It also possesses the advantage that fundamental data derivable from the observations by very simple calculation. n the other hand, a particular float only gives data at one equency for a given material, while the other apparatus ives data for a range of frequencies.

THE APPARATUS

The float is a sealed hollow cylinder, weighted so that it oats vertically and completely immersed in the gel. A narrow entred spindle attached to the float carries a galvanometer irror G and a pair of thin metal vanes V (Fig. 3). Only the pindle breaks the gel surface, so any anomalous surface ffects can have little influence on the rotation of the float. Vhen placing it in the gel, care is taken to ensure that the oat is coaxial with the containing cylinder. Two tubes T re arranged as shown so that jets of air can be directed on the vanes in order to set the float in rotation. The tube upports are mounted on a wooden annulus A which fits outide the container. From these tubes, rubber tubing leads to connecting T-piece through which the operator blows a hort blast of air. An adjustable clip on one rubber tube llows the strength of the jets to be equalized so that a purely otational motion is imparted to the float.

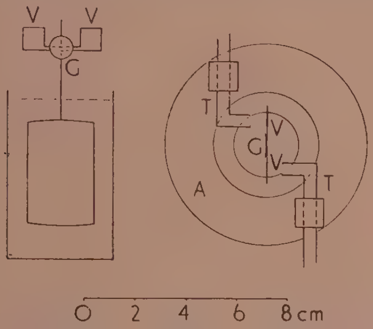


Fig. 3. Elevation and plan of float and container

A beam of light from a line-filament lamp is directed by eans of a lens on to the mirror attached to the float spindle. cylindrical lens is used to bring the reflected beam to a oint focus on a sheet of bromide paper at one metre from e mirror. This paper is carried on a horizontal drum which otates at constant speed, and time markings are provided by separate optical system.

THEORY OF THE APPARATUS

The following theory applies to a float and container of ny axially symmetrical form, and it is assumed that the asto-viscous material is a solid with linear stress-strain aracteristics. The theory is thus applicable to small scillatory motions with gels which have linear stress-strain elationships below the yield point. Such relationships may expressed as linear differential equations relating shear ress and shear strain, so that when the shear stress S varies ith time t as exp (mt), m being a constant, the shear strain varies in the same way and the relation between the two n be written as

$$\sigma = \sum_n \frac{J_n}{1 + m\tau_n} \cdot S \tag{1}$$

he constants τ_n are the retardation times of the gel and each nstant J_n represents the part of the elastic compliance associated with the retardation time τ_n. Thus the gel has an effective rigidity G_m for this type of motion, given by

$$\frac{1}{G_m} = \sum_n \frac{J_n}{1 + m\tau_n} \tag{2}$$

Cases of damped or undamped harmonic deformation can be included in equation (1) by giving m complex or imaginary values. In such cases S, σ and G_m are complex quantities and it is to be understood that the actual values of the stress and strain are respectively the real parts of S and σ.

Under the conditions here assumed, the float-gel system only involves inertia with linear elasticity and hysteresis effects. Thus free states of motion can exist in which σ and S vary as exp (mt) with certain allowed values of m. For the motion characterized by a particular value of m, both the rotation θ of the float and the restoring torque T acting upon it vary as exp (mt), it being understood that if m is complex or imaginary the actual rotation and torque are the real parts of θ and T respectively. T may therefore be set proportional to θ, the constant of proportionality depending only on m, G_m, ρ (the density of the gel) and the dimensions and geometry of the apparatus. Thus it follows from dimensional considerations that

$$T = \rho m^2 l^5 f(G_m/\rho m^2 l^2)\theta \tag{3}$$

where l is an arbitrarily-chosen dimension of the apparatus and the form of the function f depends on the geometry of the space occupied by the gel. The equation of motion of the float is obtained by setting T equal to $-Im^2\theta$ where I is its moment of inertia. This gives

$$f(G_m/\rho m^2 l^2) + (I/\rho l^5) = 0 \tag{4}$$

Since a particular float can only be used for gels of nearly the same density, ρ may be regarded as an apparatus constant like I and l. Thus it follows from equation (4) that G_m/m^2 must be equal to a certain apparatus constant having the dimensions of a mass per unit length, and the following considerations show that this must be real and negative. In the special case of a gel having no elastic hysteresis, G_m would be a real positive constant, and because there would be no energy dissipation only sinusoidal motion would be possible. In this case, therefore, m would be imaginary and hence G_m/m^2 would be real and negative. But the value of the latter quantity is independent of the particular gel properties, so in general

$$G_m/m^2 = -M \tag{5}$$

where M is a real positive constant.

For a particular gel, the allowed values of m are obtained by eliminating G_m with the help of equation (2)

$$M \sum_n \frac{J_n m^2}{1 + m\tau_n} = -1 \tag{6}$$

This is an equation of order $(n + 1)$ in m. The expression on the left-hand side rises $(n - 1)$ times from $-\infty$ to $+\infty$ for real values of m decreasing from 0 to $-\infty$. There are thus at least $(n - 1)$ real negative roots and there are obviously no real positive roots. There remain either two more real negative roots or a pair of conjugate complex roots $m = -\alpha \pm i\omega$. This shows that, after an impulsive torque has been applied to the float, it may return to its original orientation either continuously or else with an oscillatory motion, depending on the values of the constants in equation (6). In the first case the θ, t record is composed of a number of simple exponential decay curves, corresponding to those instances in which there is only a single recoil of the float. In the second case the record consists of a single curve of the form $\theta = \exp(-\alpha t).(A \sin \omega t + B \cos \omega t)$ superposed on a number of simple exponential decay curves, the presence of the latter making the oscillations unsymmetrical about the time axis. Measurements from the records show that this asymmetry is nearly always present.

Now in the oscillatory part of the motion which occurs in the second case, $m = -\alpha + i\omega$, so it follows from equation (2) that G_m is also complex and may therefore be split up uniquely into two parts as

$$G_m = G(m) + m\eta(m) \tag{7}$$

where $G(m)$ and $\eta(m)$ are *real* functions of the complex quantity m. These are respectively the dynamic rigidity and dynamic viscosity appropriate to the type of motion characterized by the value of m, and from equation (5)

$$Mm^2 + \eta(m)m + G(m) = 0 \tag{8}$$

whence

$$\left.\begin{aligned} G(-\alpha + i\omega) &= M(\alpha^2 + \omega^2), \\ \eta(-\alpha + i\omega) &= 2M\alpha \end{aligned}\right\} \tag{9}$$

But α is the decay factor and $\omega/2\pi$ is the frequency of the oscillatory part of the motion, so dynamic values of the rigidity and viscosity are directly obtainable from a record of the motion provided the apparatus constant M is known.

Unless α is very small compared to ω, the quantities given by equation (9) are not quite the same as the dynamic values $G(i\omega)$ and $\eta(i\omega)$ for pure sinusoidal motion which are usually quoted. In the case of gels, however, it is found that both $G(i\omega)$ and $\eta(i\omega)$ vary very slowly with ω, and it can be shown from equation (2) that when this is the case $G(-\alpha + i\omega)$ and $\eta(-\alpha + i\omega)$ depart inappreciably from the former quantities provided α/ω is not very large. Now it is found that if α/ω is much greater than $0{\cdot}3$, the decrement of the oscillations is so high that accurate measurements are impossible, so for all practical purposes equation (9) may be taken to give the values of $G(i\omega)$ and $\eta(i\omega)$.

In one respect the foregoing theory requires completion: It can be shown quite generally that equation (4) has not merely one solution for G_m/m^2 but an infinite series of solutions $-M_1, -M_2, -M_3, \ldots$ Hence the type of motion obtained by considering a single value of M is only one of a number of possible types. It appears, however, from the results of the calibration experiment described in the next section that one value of M is appreciably greater than the others, at any rate for an apparatus of the general design shown in Fig. 3. Since the damping increases with decreasing values of M, the most persistent type of motion is that corresponding to this largest value. In fact, the records obtained for oscillatory motion are of the simple type corresponding to a single value of M, except that the first maximum appears to be abnormally high and the first half-period of oscillation abnormally long, effects which are probably due to the presence of types of motion corresponding to lower values of M.

CALIBRATION OF THE APPARATUS

For calibration, a Newtonian liquid of the same density is used in the apparatus. After removal of the air-jet tubes, the container is rotated at constant speed until liquid and float are rotating as a whole, and it is then brought suddenly to rest. The float continues to rotate many times with gradually diminishing velocity. The beam of light reflected from the mirror on the float passes once in every revolution over the recording bromide paper. The drum is driven at slow speed so that the record appears as a series of almost parallel lines spaced at increasing intervals, and the motion of the float is plotted out from measurements on the separation of these lines.

The theory of the motion with a Newtonian liquid can be obtained formally from that given for gels by setting $G_m = m\eta$ where η is the viscosity of the liquid, and here the restriction to small deformations no longer applies. Thus it follows from equation (5) that $m = -\eta/M$, so the motion decays continuously as $\exp(-\beta t)$ where the decay constant β is given by

$$\beta = \eta/M \quad (10$$

The observed θ, t curve is by no means exponential in the early stages, but this is accounted for by the presence of a number of different exponential terms corresponding to the various values of M. There is, however, a long final period before the float comes to rest during which the single exponential law is followed closely. The decay constant β is measured for this period, and when inserted in equation (10 it gives the largest value of M which is the apparatus constant required for use in equation (9).

USE OF THE APPARATUS

The following series of measurements on rice starch pastes is given as an example of the use of the apparatus. These pastes were of various concentrations obtained by diluting a single 5 g/100 cm³ paste by the addition of further water with vigorous stirring. The density in all cases was very close to 1 g/cm³, so the same float was used for each and the calibration was made with water. The dimensions of the float were as shown in Fig. 3 and its moment of inertia was 24 g.cm². From the final decay constant β of the calibration record and the known viscosity of water, M was obtained from equation (10) as $0{\cdot}159$ g/cm. All the pastes gave oscillatory records from which the frequency $\omega/2\pi$ could be measured, the abnormally long initial half-period being omitted in calculating a mean. In order to obtain the decay constant of the oscillatory part of the motion, upper and lower envelopes were drawn to the curve on the record. After the first half-period, the difference in height between the two envelopes was found to decrease exponentially, and measurement of the decay factor gave α. The dynamic rigidity $G(i\omega)$ was then calculated as $M(\alpha^2 + \omega^2)$ and the dynamic viscosity $\eta(i\omega)$ as $2M\alpha$. The results obtained are shown below, together with values of the static rigidity $G(0)$ obtained by a torsion-wire method.

Concentration (g/100 cm³)	ω *(s⁻¹)*	$\eta(i\omega)$ *(poise)*	$G(i\omega)$ *(dyn/cm²)*	$G(0)$ *(dyn/cm²)*
1·00	0·90	0·08	0·14	—
1·25	1·13	0·10	0·22	—
1·67	3·2	0·18	1·68	—
2·50	6·7	0·41	7·4	4·5
3·33	16·0	0·80	42	39
5·00	35	1·64	200	117

These figures illustrate the large range of rigidities which can be measured with a particular float. The dynamic rigidity is found to be greater than the static rigidity, as is the case with gels in general. A particular float will only give results at one frequency for a particular gel, but single measurements of this kind are useful in giving data for frequencies of the order of 1 c/s to bridge the gap between static data and acoustic data obtained from measurements on the velocity and absorption of transverse waves in the gel.

The apparatus may be modified by replacing the float ith a heavier cylinder which is suspended in the gel by a ylon fibre having a negligible torsional constant. This rrangement has the advantages that centring is made easier nd the same apparatus can be used for gels of different ensity (although a separate calibration in each case is still ecessary).

ACKNOWLEDGEMENT

One of the authors (L. J. H.) wishes to acknowledge a grant rom the Department of Scientific and Industrial Research.

REFERENCES

(1) McDowell, C. M., and Usher, F. L. *Proc. Roy. Soc. A*, **131**, p. 409 (1931).

(2) Goldberg, H., and Sandvik, O. *Analyt. Chem.*, **19**, p. 123 (1947).

(3) Oldroyd, J. G. *Quart. J. Mech. Appl. Math.*, **4**, p. 271 (1951).

(4) Oldroyd, J. G., Strawbridge, D. J., and Toms, B. A. *Proc. Phys. Soc.* [*London*] *B*, **64**, p. 44 (1951).

Investigation of the heterodyne beat method of measurement of magnetic susceptibility

By H. G. Effemey, Assoc.I.E.E., Department of Electrical Engineering, University College, London;
D. F. Parsons, B.Sc., Ph.D.,* and J. O'M. Bockris, D.I.C., D.Sc., F.R.I.C.,†
Department of Inorganic and Physical Chemistry, Imperial College, London

[*Paper received* 29 *July*, 1954]

A heterodyne beat method of determination of unstable free radicals has been investigated. A change in the magnetic susceptibility of a liquid placed inside the coil of an oscillating circuit causes a change of frequency which is measured by beating against a quartz crystal oscillator. The apparatus has been tested by determinations of paramagnetic salts and diamagnetic liquids. It is shown that the ultimate limitation on increasing the sensitivity is the temperature control of the free running oscillator. The modification of the apparatus for the detection of free radicals of half-life times down to 0·05 s is discussed.

t is desirable, particularly in organic chemistry, to have a nethod of detecting free radicals of short life. Detection by nagnetic susceptibility measurements cannot be carried out y normal methods because of the long measurement time. Here, an examination of the applicability of a heterodyne eat (i.e. instantaneously reacting) method of measuring usceptibilities is described.(1, 2, 3, 4)

It is possible to obtain sufficient stability to detect concenrations of free radicals of only 0·005M. The limiting factor as been shown to be the temperature control of the free unning oscillator and coil.

Previous work has concerned systems in which relatively nsensitive and approximate determinations sufficed.

A change of magnetic susceptibility of a substance placed nside the coil of an oscillator causes a change in frequency which is measured by beating the oscillator against another f fixed frequency. If the volume susceptibility is κ, the hange in frequency on inserting the sample is Δf at a frequency f, the cross-sectional area of the coil is A and A' is hat of the test substance, then[illegible]

$$\kappa = \frac{1}{2\pi}\frac{\Delta f}{f}\frac{A}{A'} \qquad (1)$$

In free radical measurements the test liquid would be left n the coil, a susceptibility change produced by the generation f free radicals *in situ* giving a beat frequency charge of $\Delta f'$, whereupon analogously to equation (1),

$$\Delta\kappa = \frac{1}{2\pi}\frac{\Delta f'}{f}\frac{A}{A'} \qquad (2)$$

It is necessary to measure small susceptibility changes, e.g. bout $0{\cdot}0004 \times 10^{-6}$ c.g.s. Assuming a frequency of 100 Mc/s and $A'/A = \frac{3}{4}$, $\Delta f' = 0{\cdot}2$ c/s. Considerable frequency stability is thus required (see the discussion in the last section).

THE APPARATUS

A block diagram of the apparatus is shown in Fig. 1. The fixed frequency oscillator was crystal controlled using a 2·1 Mc/s quartz crystal in a conventional circuit (Fig. 2) followed by a buffer amplifier giving a radio frequency output of 0·75 V. The oscillator was in a brass case with double walls through which oil of 50 ± 0·001° C circulated. The stability of the oscillator was 1 in 10^8 c/s.

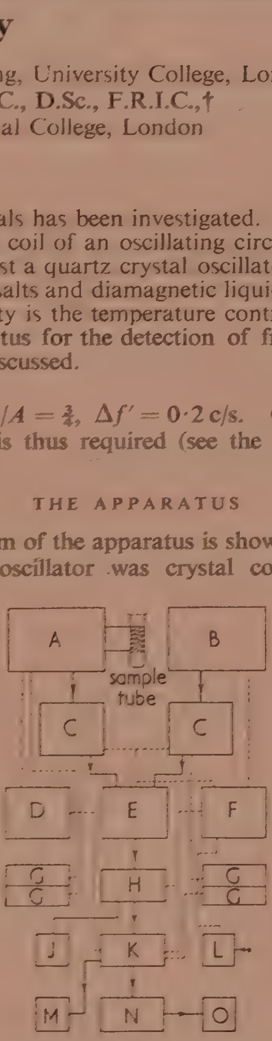


Fig. 1. Block diagram

A, critical oscillator (2·5 Mc/s); *B*, quartz crystal oscillator (2·1 Mc/s); *C*, multipliers (105 Mc/s); *D*, 100 V accumulator pack; *E*, mixer (f_1–f_2); *F*, stabilized power pack; *G*, 6 V accumulators; *H*, audio-frequency amplifier; *J*, cathode-ray oscilloscope; *K*, frequency counter; *L*, stabilized transformer; *M*, microammeter; *N*, direct-current amplifier; *O*, pen recorder.

---

* Now at St. Bartholomew's Hospital, London, E.C.1.

† Now at the Department of Chemistry, University of Pennsylvania, Philadelphia.

The critical oscillator was a Colpitts circuit (Fig. 3) followed by a buffer amplifier (output of 0·5 V at a frequency of 2·5 Mc/s). The oscillator was built in two brass cases with double walls through which oil circulated (50 ± 0·001° C).

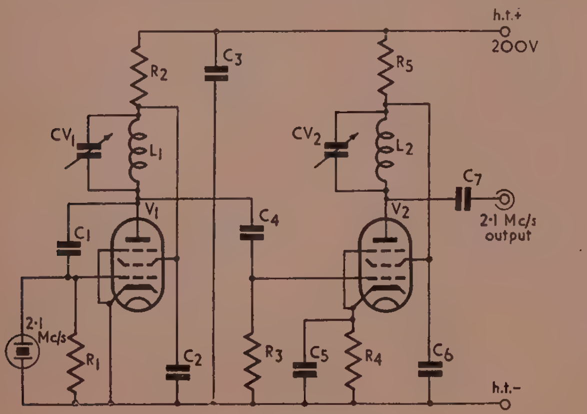


Fig. 2. Crystal oscillator

V_1, V_2 = EF91

R_1 = 4·7 MΩ
R_2 = 100 kΩ
R_3 = 1 MΩ
R_4 = 220 Ω
R_5 = 4·7 kΩ

C_1 = 1 pF
C_2 = 0·1 μF
C_3 = 0·2 μF
C_4 = 5 pF
C_5, C_6 = 0·1 μF
C_7 = 0·01 μF

One case contained the coil and was connected to the other case by a screened, low-capacity connector consisting of a brass rod (live) supported inside a brass tube. Low tension and high tension supplies had to be obtained from accumulators housed in screened boxes. Low tension leads were screened also inside the oscillator. The components had to be of the highest quality, e.g. silver ceramic condensers of negative temperature coefficient (to compensate the positive coefficient of the circuit) were unsuitable because of the indefinite edge of the silver film. V_1 in the critical oscillator had to be an anti-microphonic valve and the main tuning condenser anti-microphonic and fitted with a slow motion drive. Air in the oscillators was dried by phosphorus pentoxide.

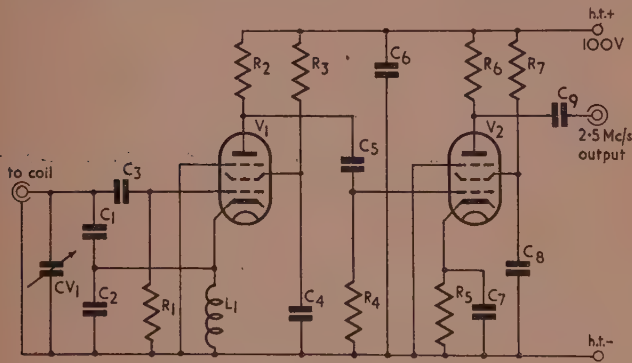


Fig. 3. Critical oscillator

V_1 = EF37A
V_2 = KTW61

R_1 = 1 MΩ
R_2 = 10 kΩ
R_3 = 50 kΩ
R_4 = 500 kΩ
R_5 = 470 Ω
R_6 = 1 kΩ
R_7 = 50 kΩ

C_1, C_2 = 400 pF
C_3 = 33 pF
C_4 = 0·01 μF
C_5 = 10 pF
C_6 = 1 μF
C_7, C_8, C_9 = 0·01 μF

CV_1 = 0–12 pF

L_1 = high-frequency choke

The frequency stability of the critical oscillator was determined by the construction of the coil(8) (Fig. 4). A quartz tube was used as a former for the coil, as it has a small coefficient of expansion ($l = 0\cdot42 \times 10^{-6}$) and low dielectric loss. The temperature coefficient of inductance was hence minimal since it is equal to l.(9) To prevent a dielectric effect caused by the sample, a film of aluminium was evaporated on the inside of the coil former. A longitudinal scratch was made to minimize horizontal circular eddy currents. The coil had 25 turns of 14 s.w.g. silver-plated copper wire spaced 1 diameter. During the winding the wire was kept under tension and a current of 20 A passed, thus giving expansion so that the coil was tight on cooling. The aluminium screen and one end of the coil were connected to the metal case. A stable connexion of the screen to the earthing bolt was essential. Oil was pumped through the coil thermostat case at 30 ± 0·001° C.

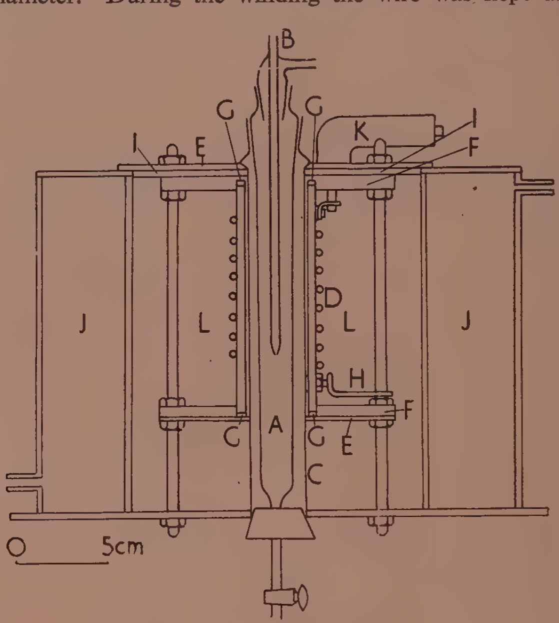


Fig. 4. Coil and thermostat case

A, sample tube; *B*, burette connexion; *C*, glass tube; *D*, quartz tube and winding (aluminized inner surface); *E*, brass plate, *F*, perspex; *G*, fibre washers; *H*, aluminium screen and coil earth; *I*, asbestos; *J*, oil space; *K*, coaxial connector; *L*, air space.

The outputs from the critical and fixed oscillators were fed to separate frequency multiplying units (Fig. 5). Each unit consisted of one amplifying stage followed by two frequency multiplying stages. In the unit fed by the crystal oscillator the first multiplying stage selected tenth harmonic and the second stage multiplied five times, giving a final output at 105 Mc/s. The unit fed by the critical oscillator, the first multiplying stage selected the seventh harmonic and the second stage multiplied six times giving a final output of 105 Mc/s. To reduce the possibility of harmonics beating before being mixed, the fixed and critical oscillators were operated at different frequencies and different harmonics were selected in the multiplying stages. The 105 Mc/s signals from the frequency multiplying units were fed into the mixer unit (Fig. 5) tuned to 105 Mc/s (a germanium crystal was used in the mixing circuit) and the output fed into the amplifier discriminator unit. The beat signal from the mixer unit was fed into a two stage amplifier which had a low pass filter in between the two stages (Fig. 6). The output from the amplifier was connected to a counting circuit based on the *Kondensator Lademethode*.(10) Provided the input to the counter was sufficient, the direct current output was independent of input voltage, and proportional to frequency below 350 c/s. This condition was assured by the double gain switch. On making the switch the frequency recorded should show no change. The output is equal to N.C.V. where N is the beat frequency, C is the capacity of the measuring condenser (Fig. 6), and *V* is a steady voltage obtained from accumulators. Germanium type rectifiers were used in the output circuit and the current amplified by a direct current amplifier and led to a recording milliammeter. The direct current output was balanced out by a potentiometer so that only small changes in frequency were measured.

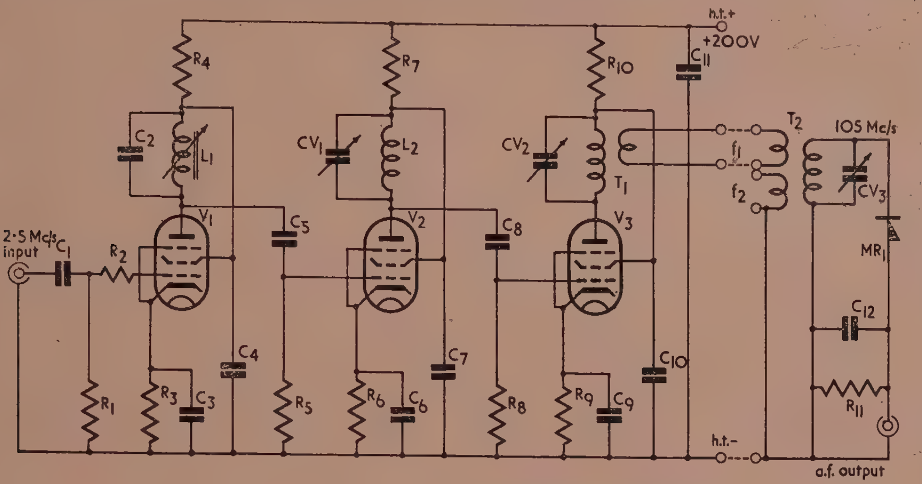

h.t.+
+200V
R4
R7
R10
C11
C2
L1
CV1
L2
CV2
T1
T2
f1
f2
105 Mc/s
CV3
MR1
C12
R11
2·5 Mc/s input
C1
R2
V1
C5
V2
C8
V3
C4
C7
C10
R1
R3
C3
R5
R6
C6
R8
R9
C9
h.t.-
a.f. output

Fig. 5. Multiplier and mixer

V_1 = N78
V_2, V_3 = EF91

R_1 = 1 MΩ
R_2 = 10 kΩ
R_3 = 150 Ω
R_4 = 4·7 kΩ
R_5 = 100 kΩ
R_6, R_7 = 1 kΩ
R_8 = 100 kΩ
R_9, R_{10} = 1 kΩ
R_{11} = 10 kΩ

C_1 = 0·001 μF
C_2 = 50 pF
C_3, C_4 = 0·1 μF
C_5 = 100 pF
C_6, C_7 = 0·01 μF
C_8 = 50 pF
C_9, C_{10} = 0·01 μF
C_{11} = 0·2 μF
C_{12} = 20 pF

CV_1 = 0–50 pF
CV_2 = 0–10 pF
CV_3 = 0–15 pF

MR_1 = CGIC

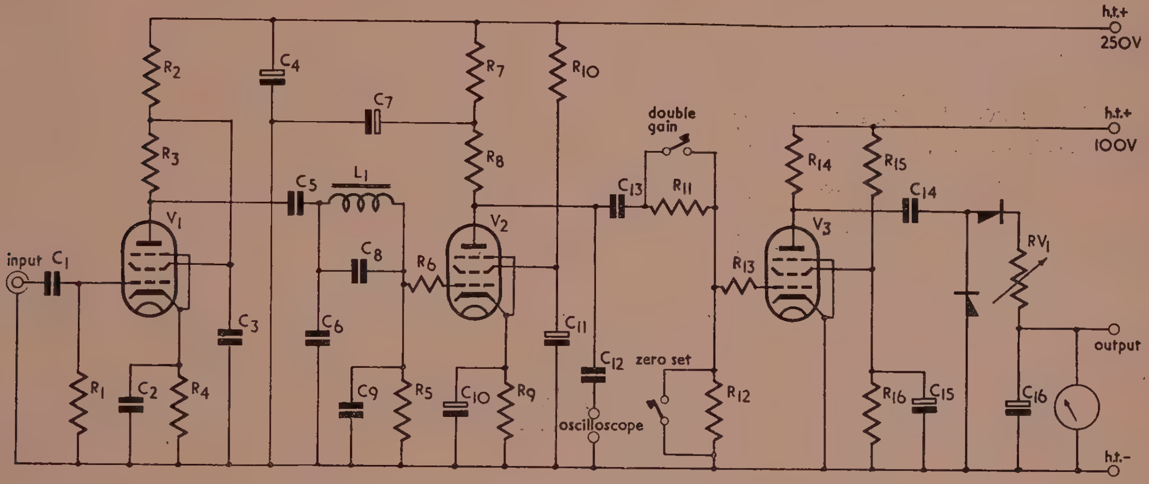

h.t.+
250V
R2
C4
R7
R10
C7
R3
R8
L1
C5
double gain
C13
R11
h.t.+
100V
R14
R15
C14
V1
V2
V3
input C1
C8
R6
R13
RV1
C3
C6
C11
C12 zero set
output
R1
C2
R4
C9
R5
C10
R9
oscilloscope
R12
R16
C15
C16
h.t.-

Fig. 6. Audio-frequency amplifier and frequency counter

V_1, V_2, V_3 = EF91

R_1, R_2 = 47 kΩ
R_3 = 22 kΩ
R_4 = 470 Ω
R_5 = 470 kΩ
R_6 = 47 Ω

R_7 = 22 kΩ
R_8 = 100 kΩ
R_9 = 220 Ω
R_{10} = 470 kΩ
R_{11}, R_{12} = 100 kΩ
R_{13} = 200 kΩ
R_{14} = 22 kΩ

R_{15} = 15 kΩ
R_{16} = 33 kΩ
RV_1 = 1 kΩ
C_1 = 0·5 μF
C_2, C_3 = 0·01 μF
C_4 = 4 μF

C_5 = 2 μF
C_6 = 0·01 μF
C_7 = 8 μF
C_8 = 80 pF
C_9 = 0·001 μF
C_{10} = 50 μF
C_{11} = 8 μF

C_{12} = 0·01 μF
C_{13} = 0·1 μF
C_{14} = 0·01 μF
C_{15} = 8 μF
C_{16} = 25 μF

L_1 = 2·05 μH

To achieve the required stability, great rigidity and careful shielding were necessary and vibration was minimized by standing the apparatus on sponge rubber. Screened leads were taken directly into the oscillator to avoid plugs. The laboratory was controlled by heaters and fans at 25 ± 0·2° C. Accumulators of the 100 V bank were kept dry and stood on wax. The oscillator and coil cases were heavily lagged. Thermostats were heated by a main heater while the regulators controlled subsidiary heaters. The coil was separated from the critical oscillator since a lower temperature for test solutions was required in the former.

TESTING OF APPARATUS

The efficiency of the inner screen of the coil was tested by comparison of liquids of approximately the same volume susceptibility κ but different dielectric constant (e.g. benzene and water). Frequency change was independent of dielectric constant.

It was hoped that the spurious frequency change due to induced eddy currents in a conducting test-substance observed by Belz(5, 6) for metals, would be insignificant for dilute electrolytes. In practice, with the high sensitivity necessary for the free radical determinations the effect was large. The eddy currents were uniformly distributed in the test solution and not concentrated at the periphery (skin effect) since the calculated skin depth(11) for a solution of conductivity of $10^{-2}\ \Omega^{-1}\ \mathrm{cm}^{-1}$ containing 90% of the current strength was

3·8 cm. Uniform reduction in the effect was obtained on insertion of glass rods of increasing diameter. Dividing the solution into eight sections by thin radial vanes reduced the effect only 4·0 times. Load compensating circuits(12) were not tried since they lead to decreased frequency stability.

The constancy of the frequency change for a given susceptibility change, $\Delta f/\kappa$, was tested by packing powdered paramagnetic salt into a glass tube and lowering into the inner tube (Fig. 4). Air correction was made.

Table 1. *Preliminary susceptibility measurements of paramagnetic salts*

	$\kappa . 10^5$ *c.g.s.*	Δf *(corrected)*	$\Delta f/\kappa$
$MnCl_2.2HO$	+207	3280	15·8
$FeSO_4.(NH_4)_2$	+ 59	905	15·3
$SO_4.6H_2O.CuSO_4.5H_2O$	+ 13·4	201	15·0
benzene	− 0·616	9·5	15·3
water	− 0·719	9·5	13·2

For diamagnetic liquids standard purification(13) and tests for iron(14) were carried out. Oscillators and thermostats were run for 2 days and accumulators were switched in 3 hours before measurements. The test solution was brought near to the coil temperature in an auxiliary thermostat and de-aerated by nitrogen. The multipliers were tuned and the beat adjusted to 100–200 c/s by condenser CV_1 (Fig. 3). As stability improved the output of the discriminator was balanced out and passed to an amplifier and recording milliammeter. When only a steady drift was present the solution was run out of the tube and the frequency change recorded. On refilling, equilibrium was established in 20–30 min. Agreement with established values was good (see Table 2).

Table 2. *Susceptibility determinations on diamagnetic liquids*

Compound	*Direct current output* µA	*Mean* Δ (*c/s*)	$\kappa \times 10^6$ (*literature values at* 30° *C*)	$\kappa \times 10^6$ (*found*)
benzene	27·5	18·7	−0·61	standard
	25·0			
	26·0			
acetone	16	11·9	−0·45	−0·36
	14			
	17			
chloroform	33	24·1	−0·73	−0·72
	34			
water	29	20·9	−0·72	−0·62

The stability of the quartz crystal oscillator was checked by replacement with an oscillator loaned by Marconi Wireless Telegraph Co. Ltd., Chelmsford, of stability better than 1 c/s in 10^8 c/s, over a day. Stability was not improved. The temperature coefficient of the combined coil and critical oscillator was $0{\cdot}58 \pm 0{\cdot}08$ c/s per 10^{-3} °C. Beckmann thermometers showed that the temperature fluctuated by less than 1/1000° C during 1 min so that a stability over this period of 0·6 c/s in 10^8 c/s was expected and observed.

DISCUSSION

The stability obtained, although probably the best recorded for a free-running oscillator, is not sufficient for useful determinations of unstable free radicals occurring in very low concentrations (see below) although the method is rapid in response. In the case of o-tolidine, investigated by the improved Rankine susceptibility balance,(1) a 0·035 M solution in 40% acetone-buffer solution (pH 2·25) gave an oxidation of 7% of free radical corresponding to a susceptibility change of $0{\cdot}003 \times 10^{-6}$ c.g.s. and this would be equivalent to a 0·3 c/s change in beat frequency which is less than the observed fluctuation due to temperature (0·6 c/s).

The coil was constructed on a quartz former of the lowest possible temperature coefficient and the temperature control was closer than any free-running oscillators previously described. The stability, however, is still inadequate for the intended purpose, although measurements on diamagnetic liquids are possible. Available negative temperature coefficient condensers proved insufficiently stable mechanically for use.

Temperature fluctuations of the coil are thus the limiting factor in the sensitivity of the heterodyne beat method and prevent its application to the measurement of free radicals in low concentration ($\Delta\kappa = 0{\cdot}0005 \times 10^{-6}$ c.g.s.). The described apparatus and technique should prove useful in other fields where very precise measurements by the method are required, e.g., dielectric constant measurement, paramagnetic relaxation studies and radio-frequency titrations.

If a high-speed recorder is used, the apparatus is suitable for measuring free radicals of half-life times down to 0·05 s provided the maximum susceptibility change exceeds about $0{\cdot}001 \times 10^{-6}$ c.g.s. With circuit modifications and cathode-ray tube presentation shorter-lived free radicals could be detected. It would then become necessary, however, to use a continuous flow method of mixing of reagents.(15, 16)

ACKNOWLEDGEMENTS

The authors wish to thank Professor H. V. A. Briscoe for facilities provided, Mr. N. Lea for discussion, and the Ministry of Supply and Marconi's Wireless Telegraph Co., Ltd., for loan of apparatus.

REFERENCES

(1) Bockris, J. O'M., and Parsons, D. F. *J. Sci. Instrum.*, **30**, p. 362 (1953).

(2) Müller, E. *Fortschr. chem. Ferschg.*, **1**, p. 325 (1949).

(3) Broersma, S. *Rev. Sci. Instrum.*, **20**, p. 660 (1949).

(4) Gorter, C. J. *Paramagnetic Relaxation* (London: Elsevier, 1950).

(5) Belz, M. H. *Phil. Mag.*, **44**, p. 479 (1922).

(6) Belz, M. H. *Proc. Cambridge Phil. Soc.*, **21**, p. 52 (1922).

(7) Gutwill, K. *V.D.E. Fachberichte*, **10**, p. 101 (1938).

(8) Lea, N. *J. Instn Elect. Engrs*, **92**, p. 261 (1945).

(9) Thomas, H. A. *J. Instn Elect. Engrs*, **77**, p. 702 (1935).

(10) Wiedemann, H. *Arch. Tech. Messen.*, V. 3613 (1951).

(11) Terman, F. E. *Radio Engineering*, p. 21 (London: McGraw Hill Publishing Co., Ltd., 1947).

(12) Broer, L. J. F., and Schering, D. C. *Physica*, **10**, p. 631 (1943).

(13) Weissberger, A., and Proskaver, E. *Organic Solvents* (London: Oxford University Press, 1935).

(14) *Reagents for "spot" tests*, p. 91 (London: British Drug Houses Ltd., 1937).

(15) Stead, Page and Denbigh. *Disc. Faraday Soc.*, No. 2, p. 263 (1947).

(16) Denbigh. *Trans Faraday Soc.*, **40**, p. 352 (1944).

The theory and design of rotating mirror cameras

By H. Edels, Ph.D., A.M.I.E.E., and D. Whittaker, B.Eng., Department of Electrical Engineering, University of Liverpool

[*Paper first received* 14 *September, and in final form* 26 *November,* 1954]

The fundamental parameters associated with rotating mirror cameras are defined and related to constants of the optical system. The effects of the mirror dimensions upon the camera properties are discussed in detail. The camera errors are defined and expressions are obtained for these errors which include the effects due to depth of field and possible defocusing of the image. The procedure for the design of a camera based upon an allowable error is developed.

1. INTRODUCTION

In order to record very fast phenomena it is often necessary to use rotating mirror cameras. Despite the rapidly increasing use of such cameras, however, hardly any detailed analysis has been published of the behaviour and errors associated with them. The investigations of Payman, Shepherd and Woodhead,(1) and Gegechkori,(2) for example, touch only briefly on the theory of certain aspects of design. We propose, therefore, to define and discuss the important parameters and performance of rotating mirror cameras. The analysis is also in many ways applicable to rotating film cameras.

The rotating mirror camera (see Fig. 1) is basically an ordinary camera, with the addition in front of the camera lens L_2 (or behind as in Fig. 1), of a rotating mirror which sweeps the image across the focal surface. If the axis of rotation of the mirror lies in the reflecting surface and is perpendicular to the optical axis SP' the focal surface is a cylinder of radius L. As pointed out by Payman, Shepherd and Woodhead, the useful portions of the focal surface are confined to the arcs P_1P_2 and P_3P_4 if all the light from the lens is to be collected by the mirror. It will be shown later that the useful portions are, in fact, even more restricted than this. Taking co-ordinate axes through the source S (as shown in Fig. 1) with the z-axis along the optical axis and the y-axis parallel to the axis of rotation of the mirror, an object moving with velocity components V_x, V_y will have an image moving with velocity components $MV_x + V$, MV_y, where M is the magnification and V the sweep velocity imposed on the image by the mirror. The gradient dy/dx, of the trace in the photographic record gives the velocity ratio $Mv_y/(Mv_x + V)$. If the phenomenon propagates in one direction only (and there are many such), then by making the y-axis parallel to the direction of propagation, the propagation velocity v_y is given by $(dy/dx)(V/M)$. For accuracy of measurement the object must approximate to a point. In most cases this is obtained by forming an image of the phenomenon on a slit with its length in the y-direction, the slit being the object upon which the camera is focused. In Fig. 1 the auxiliary lens L_1 forms the image on the slit.

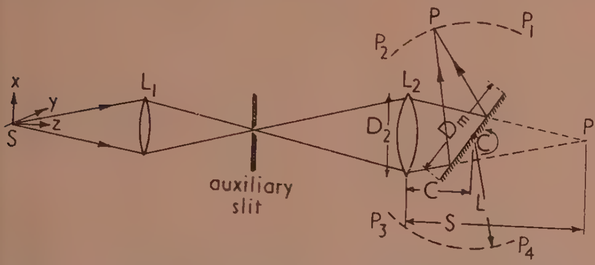


Fig. 1. Rotating mirror camera—optics with mirror on image side of camera lens

2. THE THEORY OF THE OPTICS

The performance of any camera depends upon the exposure, static image illumination and resolving power obtainable. In the case of a rotating mirror camera we are, however, concerned with a temporal resolving power and a suitable definition of this parameter is given below.

The static image illumination I. For a source of varying brightness B we obtain the image illumination I at any instant as

$$I = \frac{B\pi}{4}\left[\frac{1}{F_2(1 + m_2)}\right]^2 = B\Omega \qquad (1)$$

where Ω is the solid angle subtended by L_2 from the image position. An auxiliary relationship exists, namely

$$F_1(1 + m_1) = F_2\left(1 + \frac{1}{m_2}\right) \qquad (2)$$

where F_1, m_1 and F_2, m_2 are the apertures and magnifications of lens 1 and 2 respectively.

The exposure E. In general the exposure at t of any point of the focal plane over a total exposure time τ is given by

$$E = \int_t^{t+\tau} I dt \qquad (3)$$

The exposure time τ. The exposure time τ is given by the time of passage of the image over a point in the focal surface. Thus

$$\tau = m_2w/V = m_2w/4\pi NL \qquad (4)$$

where w is the slit width and the mirror speed is N rev/s.

The resolving power P. The definition of the temporal resolving power may be obtained from the following considerations. If we assume that an instantaneous luminous phenomenon A occurs, then this will be observed in the focal surface as an image A of width m_2w. If, now, a similar phenomenon B occurs, then this can only be completely resolved from A if a time δt is allowed to elapse, such that the slit image just moves off image A. It will be appreciated that this time δt necessary for resolution is just the exposure time τ given by equation (4), and that P is inversely dependent upon τ. We assume therefore the definition

$$P = 1/\tau \qquad (5)$$

The resolution R. If the observation of the phenomenon is continued over a total period T, then the maximum possible resolution of the total image is given by the number of separate static images which may be observed in the total image. Thus we obtain

$$R = T/\tau = P.T \qquad (6)$$

Our considerations and definitions of the camera properties lead to a relationship of fundamental importance. Thus from equations (3), (5) and (1) we obtain for constant brightness

$$E.P = I = B\Omega \qquad (7)$$

This expression shows that for a given source, the factor ($E.P$) is a constant and dependent solely upon the camera optics. For example, the exposure for a given camera may be increased by increasing w/N, but only at the expense of a like decrease in the resolving power. Independent variation of E and P may only be obtained by an alteration of the optics, the effect of which is governed by equation (1).

The effects of the mirror dimensions. In our considerations so far we have ignored the effects of the mirror width and thickness. The mirror width D_m (Fig. 1) has a controlling influence upon the position of the mirror relative to the camera lens. Thus since for a given value of m_2 and hence of ($E.P$) it is advantageous to use a maximum possible value of L (Fig. 1) giving a minimum curvature of the focal surface and a minimum mirror speed for a given sweep speed, we place the mirror as close as possible to the lens. Thus allowing for the lens thickness so that $c \simeq D_2$ we obtain

$$L = s - c = D_2[(1 + m_2)F_2 - 1] \qquad (8)$$

Since the minimum value of L is $D_m/2$ and we may take $D_m \simeq \sqrt{2}D_2$ we find that the minimum value of $F_2(1 + m_2)$ $\simeq 1 \cdot 7$. Lower values of $F_2(1 + m_2)$ can only be accommodated by placing the mirror on the object side of the lens as shown in Fig. 2. An important limiting feature of this system is that the useful portion of the focal surface is considerably restricted if no light is to be lost when the mirror rotates. For example, the mirror can only turn through 3° before light is lost, if we utilize 0·9 of the available aperture. It will be seen from Fig. 2 that the focal curve for the source S is a circular arc of radius l_2 which can be shown to closely approximate to l, for the small mirror rotation allowed, if the lens produces a plane image from a plane object.

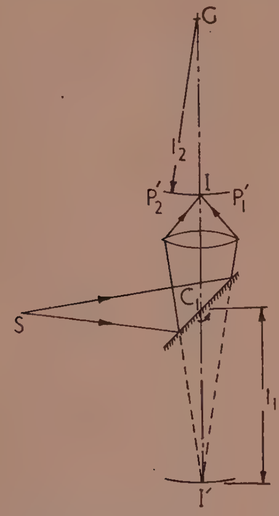


Fig. 2. Rotating mirror camera—optics with mirror on object side of camera lens

Considering now the sweep speed, we note from Fig. 2 that the real image will have a speed of $4\pi N l_1 m_2$ and hence the effective lever arm is $L' = m_2 l_1$ which gives with $c = D_2$ an expression to be compared with equation (8)

$$L^1 = D_2[(1 + m_2)F_2 - m_2] \qquad (9)$$

If we compare the systems of Figs. 1 and 2, we find tha when the lens mirror distance is the same in both systems an if $m_2 < 1$ then $L^1 > L$ so that a greater sweep speed is possibl with the system of Fig. 2. Also on the basis of achievin equal sweep speeds in both cases then we find that $l_1 = L/m$ so that a reduced curvature of the focal surface is achieve with Fig. 2. These advantages are, however, offset by th reduction in the useful aperture of the system and by th restricted focal surface available.

For high mirror speeds it is not advisable to set the axis of rotation in the plane of the mirror surface. Normally th mirror will be of uniform cross-section so that the separatio of the surface from the axis will be half the mirror thickness It will be shown that this finite separation produces a non cylindrical focal surface and a variable image sweep speed.

Thus in Fig. 3 the mirror is shown situated on the image side of the lens (although the following discussion applies t both the systems shown in Figs. 1 and 2), and the separation of the surface and axis is b whilst the point of focus is at P. The instantaneous centre of rotation of the mirror surface M is F, whilst the reflected ray R rotates about E (not K as stated by Payman, Shepherd and Woodhead) where $\angle FEK = 90°$.

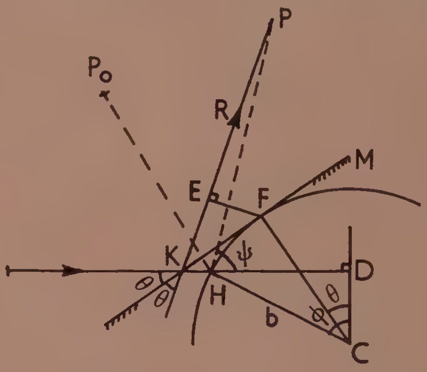


Fig. 3. Conditions at mirror of finite thickness

Now for a given value of b and distance CD the angle ϕ and the point H are determined. If now we use a subscript 0 to denote the reference condition $\theta = \phi$, then changes in optical path p with varying θ are given by $dp = p - p_0$ and changes in HP by $d(HP) = HP - HP_0$. Analysis then shows that for an extension of P over 120° an error of <1% is made if we take

$$dp = d(HP) + 2b \sin\theta(\cos\overline{\theta - \Phi} - 1) \qquad (10)$$

It can be shown also that with an error of less than 1%

$$dL = d(HP) + b(\sin\overline{2\theta - \phi} - \sin\theta) \qquad (11)$$

From equations (10) and (11) we obtain an auxiliary equation

$$dL - dp = b(\sin\theta - \sin\phi) \qquad (12)$$

and since the condition of perfect focusing is $dp = 0$ and for constant writing speed $dL = 0$, this expression shows that it is impossible to satisfy these two desirable conditions simultaneously, over any working range of θ. It will be appreciated, however, that the optimum range is with θ near 90°, so that it is preferable to work with the reflected cone of light just clearing the camera lens.

For convenience, equation (10) is plotted in Fig. 4(a) as a family of P curves, and equation (11) in Fig. 4(b) as a family of L curves, with ϕ as a parameter. If it is desired to maintain erfect focus, then $d(HP)$ is obtained from the P curves by utting $dp = 0$. From these values of $d(HP)$, the L curves ive the expected variations in writing speed, and since it is ufficiently accurate to take $\psi = 2\theta$ the locus of P is easily btained. Alternatively, to obtain constant writing speed, (HP) is obtained by putting $dL = 0$ in the L curves, and the efocusing is found from the P curves.

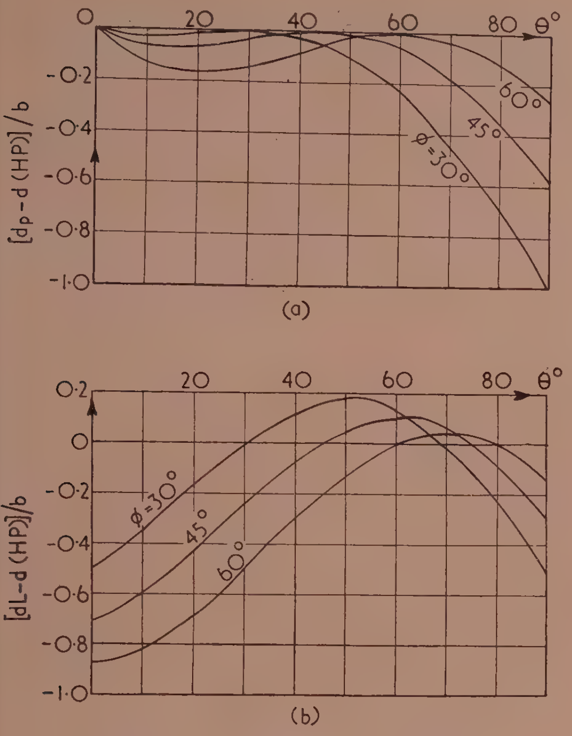


Fig. 4. (*a*) *P* curves; (*b*) *L* curves

. MEASUREMENTS AND MEASUREMENT ACCURACY

Two main types of measurement are possible with the amera, namely, measurement of the velocity of propagation f a phenomenon across the field of view, and the deternination of the temporal intensity variation of these phenoena. In both forms of measurement the camera imposes a mit on the accuracy of measurement.

The measurement of propagation velocities. As indicated Section 1 a phenomenon moving with a variable velocity v ill trace out a path in the focal plane of the camera such hat the tangent to the path is given by

$$\tan \alpha = Mv/V \qquad (13)$$

f during a time T both v and V are constant then a photoraphic record will give a line AC' (Fig. 5) at α to the direction f the sweep. Using an auxiliary, stationary light source the ne of sweep AD may be obtained. It will be seen that the ccuracy of measurement of v depends upon the errors rising in the determination of V, M and α. Of these errors nly that associated with α is seriously dependent upon the amera design.

From equation (13) we obtain the fractional error in easuring v due to an error $d\alpha$ in measuring α as

$$e = dv/v = 2d\alpha/\sin 2\alpha \qquad (14)$$

There are three possible errors which sum to give $d\alpha$, namely, the errors $d\alpha_1$ in determining the position of AC', $d\alpha_2$, in determining AD, and $d\alpha_3$ in determining the angular rotation between AC' and AD. Both $d\alpha_2$ and $d\alpha_3$ are independent of α and may be reduced to 0·1%. To determine $d\alpha_1$, we note that the line AC', owing to the finite width of the auxiliary slit, is broadened into a band of varying density shown as $AC'D'B$ (Fig. 5). Thus if we assume that the brightness and intensity of the image before and after the arrival of the phenomenon are B_1, I_1 and B_2, I_2 respectively, then the exposure and density along any line parallel to the sweep axis are $E_1 = I_1\tau$ and D_1 before reaching AC' and $E_2 = I_2\tau$ and D_2 after leaving BD'. Between these limiting values consideration shows that the exposure variation is linear, so that lines of constant exposure, and hence constant density, are made at α to the sweep axis. The corresponding density variation is, however, non-linear. From this it will be clear that the maximum value of $d\alpha_1$ is given when measurement is made over the extreme density change $(D_2 - D_1)$ and in terms of the normal to AC' is $d\alpha_1 = n/\lambda$. It is possible, however, to detect a density change $\delta D \ll (D_2 - D_1)$ so that the value of $d\alpha_1$ may be reduced to $\delta n/\lambda$. Now, assuming that the linear portion of the photographic characteristic is used, it can be shown that if δD is measured about the position of mean exposure, the relationships $\delta n/n = \delta E/(E_2 - E_1) \simeq \delta D/(D_2 - D_1) = \delta D/(\gamma \log B_2/B_1)$ may be assumed with an error of less than 10% if $E_2/E_1 \leqslant 4$. Analysis then gives the camera error

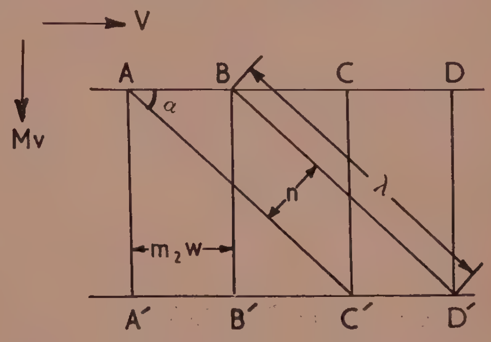


Fig. 5. Image formation with finite slit width

$$e' = 2d\alpha_1/\sin 2\alpha = \delta D/(P.T.\gamma \log B_2/B_1) \qquad (15)$$

and the total error

$$e = [\delta D/(P.T.\gamma \log B_2/B_1)] + [2(d\alpha_2 + d\alpha_3)/\sin 2\alpha] \quad (16)$$

where γ is the contrast of the photographic emulsion. Since $d\alpha_2$ and $d\alpha_3$ are independent of α, e is minimized by making $\alpha = 45°$.

The expression indicates that the camera performance is essentially dependent upon the resolving power and that hence our original definition is satisfactory.

Errors due to defocusing and depth of field. Defocusing and depth of field produce a broadening and density change in the band $AC'D'B$ (Fig. 5) so that the error $d\alpha_1$ is affected. Defocusing will be caused by relative movement of the slit, lens 2 and the photographic plate P. If the plate is out of focus by a distance σ then the diameter of the circle of confusion is $d_1 = \sigma/F_2(1 + m_2)$ and the camera error is increased to $e_1 = e'(1 + \Delta_1)$. The correction term Δ_1 may be obtained from Fig. 6(*a*), the curves of which are based on the assumption given above that $\delta n/n \simeq \delta D/\gamma \log B_2/B_1$.

The effect will now be examined of having an object with a finite depth along the optic axis of $2r$ with an extension of $\pm r$ about the object plane. Considering the light originating from a plane, distance ρ from the object plane, and assuming perfect focusing, then the diameter of the circle of confusion is $d_2 = \rho M^2/F_2(1 + m_2)$. For an extended source the exposure distance curve is found by integrating the light from planes in the range $r > \rho > 0$. These calculations have been made and a correction term Δ_2 may be found in this case from Fig. 6(*b*), where the absicissa is $d_2 \cos \alpha/n$ and $d_2 = rM^2/F_2(1 + m_2)$. We thus obtain a camera error given by $e_2 = e'(1 + \Delta_2)$. A good approximation for the combined effects of both defocusing and depth of field is obtained by summating the Δ terms giving a final error

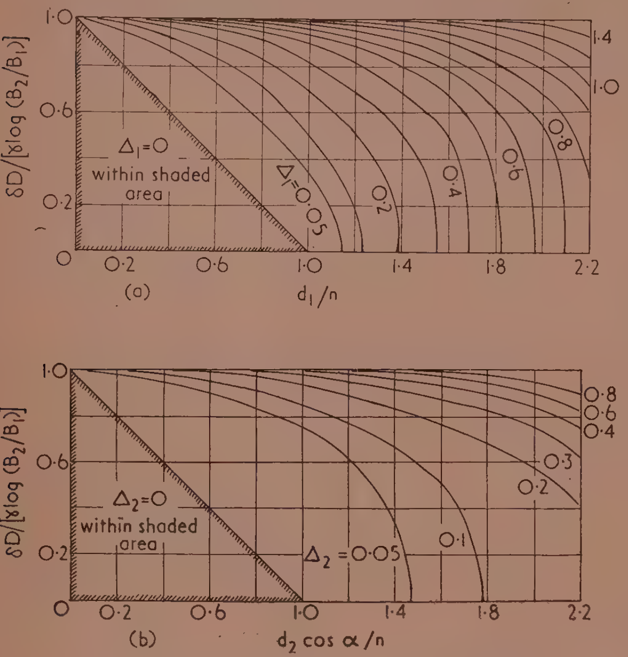


Fig. 6. (*a*) Curves of error due to defocusing; (*b*) Curves of error due to field depth

$$e = \frac{\delta D(1 + \Delta_1 + \Delta_2)}{P.T.\gamma \log B_2/B_1} + \frac{2(d\alpha_2 + d\alpha_3)}{\sin 2\alpha} \tag{17}$$

It will be seen that we may define an effective resolving power given by $P_{eff} = P/(1 + \Delta_1 + \Delta_2)$.

The measurement of intensity and the associated error. The camera produces from an intensity/time variation, an exposure/sweep variation governed by equation (3). By expressing $I(t)$ as a Taylor's series it may be shown that a fractional error in the reproduction of intensity $\delta I(t)/I(t)$ exists which is proportional to P^{-n} where $n \geqslant 2$. It is of interest to note that if $I(t)$ is of less than cubic order, exact reproduction is achieved.

4. THE DESIGN OF A CAMERA

Utilizing the theory developed above, a general formulation of a method for designing a rotating mirror camera will now be given. It is clear that the achievement of both high accuracy and the recording of faintly luminous phenomena is obtained by the use of an optical system having a high value of $(E.P)$ and hence a low value of $F_2(1 + m_2)$. It is desirable, however, to be able to determine the actual value of $(E.P)$ required for accurate recording and this is most suitably achieved by design based upon the maximum error allowable in th instrument.

To commence the design we assume a preliminar knowledge of the order of the propagation velocity v, th duration T and the brightness ratio B_2/B_1. We require furthe the results of an auxiliary experiment which gives the value o $P[F_2(1 + m_2)]^2$. In this experiment a source of brightness is focused as a static image on to a photographic plate of th type to be used. With a given aperture F and magnificatio m the exposure time t is chosen so as to obtain the require photographic density, thus

$$\frac{4E}{\pi B} = \mu t/[F(1 + m)]^2 = 1/P[F_2(1 + m_2)]^2$$

The factor μ accounts for the failure of the reciprocity la since normally $t \gg \tau = 1/P$. Indications of the value of μ t be used for particular cases may be found by reference, fo example, to the work of Wallis and Beatt.(3)

If now we assume an allowable error e, estimate the value of $d\alpha_2$ and $d\alpha_3$ and take an initial value of $\alpha = 45°$, equatio (17) gives the value of $[\delta D(1 + \Delta_1 + \Delta_2)]/(P.T.\gamma \log B_2/B_1$ Ignoring the Δ terms, since they depend upon unknow values of F_2 and m_2, we obtain a first value of P by insertin estimates of δD and γ. Utilizing the results of the auxiliar experiment and the value of P we find the required facto $F_2(1 + m_2)$ for which suitable values for F_2 and m_2 may b chosen. As indicated in Section 2, if $F_2(1 + m_2) < 1{\cdot}7$ th mirror must be placed on the object side of the camera lens Now the Δ terms are dependent on M and this for a given is related to the sweep speed V. It may be noted that it i desirable to use as large a value of V as practicable in orde that the maximum value of M may be obtained since thi will minimize the problem of photographic grain size. However, M should not normally be greater than unity, sinc from equation (2), when $M > 1$ then $F_1 < F_2$ and such a optical system will be relatively inefficient with respect to th values of $(E.P)$ obtainable with the two lenses used. No the maximum velocity V is determined by the maximu permissible stress set up in the mirror which is proportiona to $(N.D_m)^2$. Since $V = 4\pi NL$ we find that

$$V_{max} = 4\pi(N.D_m)_{max}(D_2/D_m)[F_2(1 + m_2 \; - m_2]$$

With the mirror working in the range $\theta \simeq 45°$, $D_m \simeq \sqrt{2}D$ so that V_{max} may be determined and hence values of w and obtained [equations (4) and (13)].

With the data thus obtained and $n = m_2 w \sin \alpha$, estimate values of σ and ρ allow us to obtain the first values of Δ_1 an Δ_2 from Figs. 6(*a*) and (*b*). If these Δ terms increase th camera error appreciably, new values of P, F_2 and m_2 mus be obtained until successive approximations give the desire result.

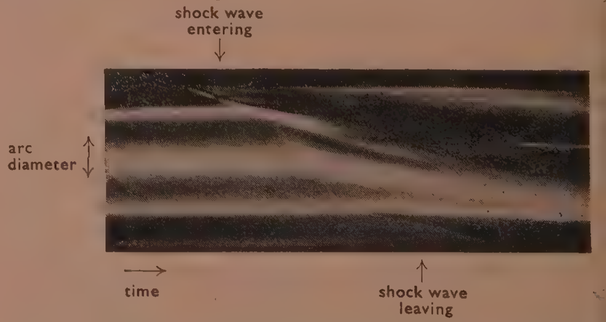


Fig. 7. Record of shock wave propagation through a carbon arc in air

The final details of the design, namely values of L, N, m d F_1, may now be calculated. If the field of interest in the ject plane is not small, either a smaller value of F_1 than at given by equation (2) will be required or a field lens may placed near the slit of such power as to form an image of in L_2. From the mirror dimensions and position we may e Fig. 4 to plot the required focal surface.

A typical record obtained with a camera designed in this anner is shown in Fig. 7. By combining a Schlieren system th the camera we recorded the propagation of a shock wave om regions outside and through a carbon arc in air.

ACKNOWLEDGEMENTS

The authors would like to record here their appreciation of e interest shown in this work by Professor J. M. Meek and Dr. J. D. Craggs. They are grateful also to Miss D. M. Garfitt for discussions held and for the camera in its original form. One of us (D. W.) is grateful to the University of Liverpool for the award of a University Fellowship, which made this work possible.

REFERENCES

(1) Payman, W., Shepherd, W. C. F., and Woodhead, D. W. *Safety in Mines Research Board Paper No.* 99 (1937).

(2) Gegechkori, N. M. *J. Exp. Theor. Phys., USSR*, **21**, p. 493 (1951).

(3) Wallis, E. G., and Beatt, A. A. G. *Inst. Brit. Photogr. Rec.*, **30**, p. 236 (1951).

A driving unit for a "time-lapse" ciné camera

By A. F. Hughes, Sc.D., and W. R. Hughes, Anatomy School, University of Cambridge

[*Paper first received* 4 *October, and in final form* 8 *November*, 1954]

A driving mechanism for a "time-lapse" ciné camera is described which is used in making speeded-up films of living biological material under a microscope. A positive intermittent drive is given to the camera, such that the film is moved on one frame and a single exposure made on each occasion. The intervals between exposures can be varied by a system of switches.

ime-lapse" cinematography is a well-known technique in ich successive exposures on ciné film are made at relatively ng intervals and the resulting record is subsequently viewed means of a normal projector running at the standard eed. In the study of living biological material under the croscope this general method is very useful, not only to cord the changes which occur within the preparation, but o to reveal any movements which are too slow for an server to apprehend directly. In recent years, the intro-ction of the phase-contrast microscope has given a fresh petus to researches of this kind.

The apparatus required consists of a ciné camera, usually 16 mm film, mounted over a microscope with optical angements for focusing the image in the plane of the film. me form of intermittent drive for the camera is necessary that a single frame of film can be exposed at selected ervals. Some arrangements for this purpose use the ing motor of the camera itself, which is controlled by an apement mechanism. Others use an external drive such a small electric motor which is on open circuit during the erval between successive exposures.(1) At the end of this erval contact is made by a master timing mechanism and camera is turned through the cycle of a single exposure. e circuit is then again broken by means of a switch actuated a cam in the camera mechanism. This second switch is parallel with that of the master controller which closed the tor circuit in the first instance. By this means the camera chanism comes to rest at approximately the same point, dy for another cycle when the circuit is again closed.

The disadvantage of this arrangement is that the timing of camera gear is dependent on the momentum of the motor. e camera switch must cut-off at a point such that the nainder of the cycle is accomplished while the motor is wing to rest. As it becomes warmer during use, and the cosity of its lubricant decreases, the point in the camera le at which the mechanism comes to rest will advance by ew degrees, and may proceed so far that control of the timing cycle is lost. For this reason, if the motor is a universal one, it is desirable to include in its circuit a rheostat or an auto-transformer to keep the point of rest approximately constant.

A more accurate principle is to keep the driving motor continuously rotating and to couple it to the camera by some form of clutch, controlled automatically from the master timing gear. It is necessary to incorporate some system whereby the drive is engaged and freed at the same points in the revolution of the main shaft. A suitable arrangement is described in a book edited by Jones.(2) Two coaxial drums are free to revolve independently; one rotates continuously, the other is connected to the driven mechanism. They are both enveloped by a coil spring, one end of which is attached to a wheel free to turn in the same axis as the drums. If this wheel is held stationary by a stop, these drums will not engage, but when this stop is released the spring will wrap tightly round both drums; and they will rotate together until the wheel is once more halted by the stop. Thus a momentary release of the stop will result in a single turn being made by the second drum. There is no tendency towards cumulative error on repeated actuation and the rate of revolution is constant for a given motor speed.

In Fig. 1 are shown the details of such a clutch mechanism suitable for driving a 16 mm camera. A and B are the two drums, and their shafts revolve in bearings D; C the release wheel and E the coil spring. At the inner end E is fixed to C by the pin K. C is controlled by a pawl J, actuated by the solenoid L.

It was found that the clearance between the spring and the drums is all-important for securing an instantaneous take-up once the mechanism is released. For this reason, the spring should be wound first and the drums afterwards turned to fit. The spring is formed of twenty-four coils of steel wire, 19 s.w.g. wound in a left-handed spiral. It is approximately 1 in. in length. Drum B should be 0·001 in. larger in diameter than the internal diameter of the spring when free; drum A

should be the same diameter as *B* at the point where both are in contact and should increase by another 0·003 in. at the other end.

To maintain the closeness of contact between spring and drums, it was found desirable to enclose the outer surface of the spring in two sleeves *F* and *H*, which has the further advantage of retaining oil and keeping the mechanism free from dust. *H* is clamped to the further half of the spring by a grub-screw *G*.

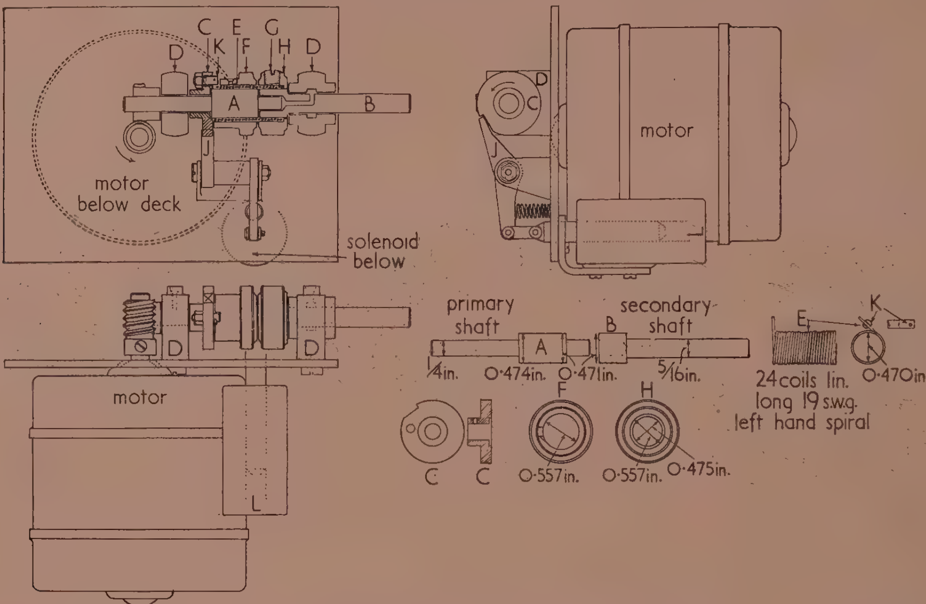


Fig. 1. Details of clutch mechanism for camera driving unit

The clutch mechanism is mounted on the upper surface of a brass plate, on the lower face of which is the motor and the solenoid. The motor used, a Hoover Type S.P. 302, drives the clutch shafts through a worm gearing at approximately 20 rev/min. It is also used to drive the controlling gear for the whole apparatus, the arrangement and circuits of which are shown in Fig. 2. A secondary shaft (1) bearing cams revolves at 3·3 rev/min, driven by a 6 : 1 gear from the primary clutch shaft. These cams control mercury switches (2) and (3) which vary the interval between successive exposures. They close a circuit through a low-voltage rectifier (4) and solenoid *L* (Fig. 1). With the clutch continuously engaged and the camera drive turning without interruption, forty exposures per minute are obtained. If both switches (2) and (3) in Fig. 2 are free to operate, three exposures are made during one revolution of shaft (1); if switch (3) is held in the off position, then switch (2) gives a single exposure in this cycle. When a film is exposed under these conditions and afterwards projected at sixteen fram per second the resulting factors by which events are "speede up" are 24, 96 and 288 times respectively.

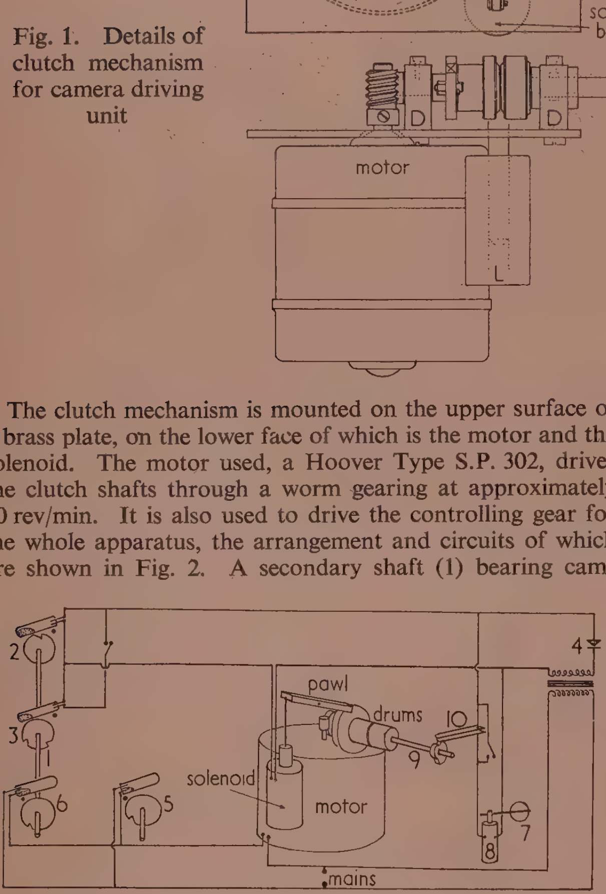


Fig. 2. Circuit diagram of clutch mechanism

Longer intervals between exposures can be contrived means of a further mechanism, which has a master switch (closed at relatively long intervals and which is in paral with switch (6) on shaft (1). By this means shaft (1) mak a single revolution whenever switch (5) is closed. Switch (breaks contact in the driving motor circuit and ensures th the clutch mechanism comes to rest at the same positi each time. It would, of course, be possible to use a electronic timer in place of these mechanical switches.

One further switch mechanism can be contrived to interru the illumination of the object under the microscope betwee exposures. Often the sensitivity to light of the living obje is the limiting factor in the whole technique of ciné phot micrography, and it is important to cut off the light to t microscope whenever possible. This is better done by inte posing a shutter in the path of the light beam than by openi and closing the lamp circuit. A simple arrangement of disk of metallic foil (7) controlled by an electromagnet (8) adequate, such as was described in the previous paper.[(1)] C shaft (9) (Fig. 2) is mounted a suitable cam bearing on switc contacts (10) which energize the solenoid through the sam low voltage source as is used for the electromagnet whic releases the clutch mechanism. Any suitable ciné camera which a shaft geared directly to the gate mechanism accessible to an external drive can be used for this purpos Preferably this shaft should give one camera frame per tur The camera used by the authors, however, is a convert R.A.F. "G45" model, in which an external drive was arrange through an intermediate pinion, half a turn of which corr sponds to one camera frame. It was thus necessary cut two notches 180° apart in the wheel *C* (Fig. 1) to ensu that the driven shaft *B* makes a half turn at each release.

REFERENCES

(1) Hughes, A. F. *J. Roy. Micro. Soc.*, **69**, p. 53 (1949).
(2) Jones, F. D. (ed.). *Ingenious Mechanisms for Designe and Inventors*, Vol. 1, p. 140 (Brighton: Industrial Pres 1951).

An adiabatic calorimeter for measuring the specific heats of liquids in the range 0 to 100° C

By L. W. PHIPPS, B.Sc., A.R.C.S., A.Inst.P., Physics Department, The National Institute for Research in Dairying, University of Reading, Berks.

[*Paper first received* 30 *November, and in final form* 14 *December*, 1954]

A calorimeter of the adiabatic type is described, capable of measuring the specific heats of liquids within small temperature intervals (2 or 3° C) over the range 0 to 100° C. An accuracy of ±0·5% can be maintained throughout the full working range, with a small increase in precision between 10 and 30° C. Features of the design include: an electrically heated annular metal jacket; stirring of the calorimetric fluid (125 ml.) by an oscillation of the calorimeter about its vertical axis (this has certain advantages over the conventional motor-driven shaft and paddle); a calorimeter heater design giving wide dispersal of heat without local overheating; ease of assembling and dismantling. Primarily designed for measurements on liquid dairy products, it can be used for other liquids. Typical results with the former are illustrated.

dies of some of the physical properties of the dairy ducts, milk, butter, cheese and their variants, have resulted the development of tests and techniques now well-estab- ied in the dairy and laboratory. In the case of milk, such perties as specific gravity, freezing-point and viscosity, and ir relationship to various milk assessing and processing thods have received considerable attention. The thermal haviour and the physical state of the fat in mass and in bular form in milk, has also been studied in some detail. the other hand, fundamental thermal data for even the ical dairy products are scanty and results that are available not always concordant. Moreover, measurements are en confined to limited temperature ranges. Fleischmann,(1) mmer and Johnson(2) and others report values for the cific heat and thermal capacity of milk and creams. Their ults however are, in the main, average values over fairly ge temperature intervals, and variations with temperature ve often been obscured in their generalization of the results. me disagreement exists over values for creams.

The calorimetric work to be described was designed with a w to investigating in detail certain of the thermal properties the liquid dairy products and, in particular, the specific at/temperature relationship from 0 to 100° C, and modi- ations to this as a result of varying composition and thermal tory of the samples.

A method was aimed at which would enable specific heat erminations to be made, not with extreme accuracy, but about ±0·5% within small temperature intervals over the ole range. The need for an approach to true specific heats s considered necessary in order to be able to delineate the ent heat effects encountered with fat-containing materials. rthermore, the method was to be capable of following cific heat changes during slow thermal equilibration. is is important, as the complex mixture of glycerides nprising the fat which occurs in milk, for example, and its persal into individual globules and not a continuous phase, n lead to long-term thermal instability, the time to reach rmal equilibrium depending upon the temperature at ich the sample is held.(3)

An adiabatic arrangement was chosen as appearing best ted to protracted experiments over the temperature range uired. The principles of design to be observed in orimetry generally, including the adiabatic method, are ll known and have been studied and discussed by White,(4) rtevant(5) and many others. Features incorporated in the sent apparatus in addition to those mentioned, and erned to some extent by the nature of the materials for t, are:

(*a*) a small calorimeter (125 ml.) as limited quantities of material are available;

(*b*) a closed calorimeter to obviate evaporation during extended working periods;

(*c*) a calorimeter heater of such a design that the sample temperature can be raised 2 or 3° C in a few minutes without giving rise to intense local heating. By avoiding local overheating, the possible introduction of metastable states in any fat content is minimized;

(*d*) rapid working through the temperature range when not otherwise concerned with such slow processes as latent heat phenomena;

(*e*) ease of assembling and dismantling the apparatus.

THE PRINCIPLE OF THE METHOD

The general arrangement of Fig. 1 shows the calorimeter *A* supported inside the electrically-heated jacket *B*, the whole assembly being fixed centrally on a platform *C* capable of oscillation about its vertical axis *YY* coaxial with the calorimeter and jacket. This action, in association with fixed metal fins inside the calorimeter, promotes stirring of the liquid. Methods of stirring involving movement of the calorimeter have been used by other workers,(6,7) but the present arrangement avoids some of the difficulties they encountered. There are several advantages to be gained by this apparent elaboration of the conventional motor-driven shaft and paddle. No difficulties arise in complete closure of the calorimeter and the latter can be small and easily accessible; attachments to the calorimeter are kept to a minimum and opportunities for conductive heat leakage to and from it are consequently reduced; the effective water equivalent of the calorimeter and accessories is kept low.

Temperature equality of jacket and calorimeter is indicated by no out-of-balance deflexion on a mirror galvanometer connected to two fine-wire thermocouples arranged differentially. One thermocouple is attached to the outer surface of the calorimeter and connected in opposition to the other, fixed to the inner wall of the jacket. Temperature control of the jacket is exercised by varying the current through its heater, either manually or electronically, so as to maintain the conditions of balance.

The apparatus on the platform is enclosed by a Perspex box *D*. The temperature of the air inside the enclosure is maintained at approximately the working temperature of the calorimeter and jacket. Below room temperature this is attained by means of refrigerating coils, and above by an electric heater. This arrangement allows fully adiabatic conditions to be established and maintained at any working temperature.

The method of making a specific heat determination follows the usual procedure. Adiabatic conditions are maintained whilst a measured quantity of heat is supplied to the calorimeter and the resulting temperature rise measured with a thermoelement. These measurements, together with a knowledge of the mass of liquid and the water equivalent of the calorimeter and accessories, enables the mean specific heat of the liquid over the observed temperature interval to be determined in the usual way. Detailed examinations of particular features, for example a latent heat "hump," can be facilitated by taking the temperature readings in the final period of one run, as those for the initial period of the succeeding one.

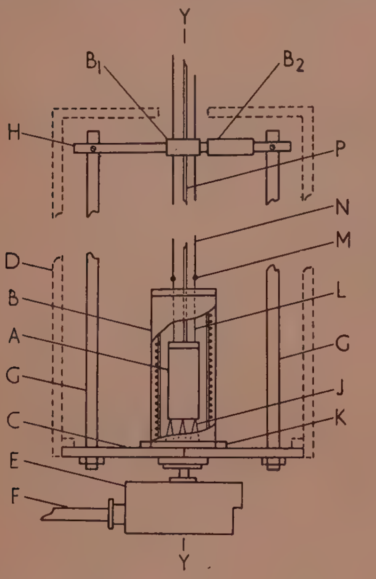


Fig. 1. General arrangement of the apparatus

CONSTRUCTIONAL DETAILS

General. Referring to Fig. 1, a windscreen-wiper type gear box *E*, operated by a flexible drive *F* from a variable speed geared motor is supported rigidly in a metal framework. The Tufnol platform *C* (about 8 × 8 × ⅜ in.) is firmly mounted at its centre on the vertical driving shaft of the gear box, thus enabling a rotary oscillation to be imparted to it. The amplitude of oscillation is about 100° whilst the period is variable, but usually arranged to be about 2 s. Two Duralumin rods *G* bolted to the platform serve to support the Tufnol cross-member *H* which carries two terminal blocks B_1 and B_2. The jacket *B*, with the calorimeter *A* supported inside on three Bakelite pillars *J*, is mounted centrally on the platform and held firmly in position by three small clamps *K*. The clearance above the jacket is sufficient to allow it to be raised (without its bottom plate) and supported, thus giving access to the calorimeter. The calorimeter heater leads *L* pass out through the top plate of the jacket and are soldered just outside the latter, at *M*, to two 16 s.w.g. copper down-leads *N* held firmly in the terminal block B_1. Connexion is made from B_1 to the calorimeter heater supply circuit by 16 s.w.g. enamelled copper wires. The heating elements for the cylinder, and top and bottom plates of the jacket, are connected in series and then *via* terminal block B_2 to an a.c. or a d.c. supply (connexions not shown). A ten-junction thermoelement *P*, for measuring the calorimetric fluid temperature, passes through a hole in t top plate of the jacket and is inserted into a steel tube in t calorimeter. Leads from the two opposed thermocoupl pass out through another hole in the top plate. All lea from the platform assembly are gathered together central above the apparatus, taken up a short distance and support in a clamp. The box *D*, of ¼ in. Perspex, is hinged along o vertical edge and can thus be "halved" for easy removal.

The calorimeter. Hunziker,[(8)] summarizing work on t chemical action of milk upon various metals, finds little no contamination of milk with heavily tinned copper or bras or stainless steels. As facilities were available for machini the latter, this was used for the body of the calorimeter. T cylindrical vessel, highly polished on the outside, is 3¾ i long and 1¾ in. in diameter, with a wall thickness of abo 0·015 in. Three countersunk brass feet are soldered to t base of the calorimeter, enabling it to stand rigidly on t three Bakelite pillars within the jacket.

A well fitting drop-on lid, also of stainless steel, carries t heater assembly shown in Figs. 2(*a*) and (*b*). A thin-walle stainless steel tube *Q* (3½ in. long, $\frac{3}{32}$ in. internal diameter) silver-soldered to the lid *S*, which is drilled centrally receive it. This tube holds the thermoelement for measuri the temperature of the liquid. Each of the two brass disks silver-soldered to the tube as shown, is drilled radially receive nine glass-insulated steel pins. Each pair of corr sponding pins on the disks serve as supports around which heating element *U*, of 31 s.w.g. constantan wire, is woun The resulting nine heating elements are connected in paralle one end of each element being soldered to the extremity its upper steel support and so "earthed" to the calorimet body, while the remaining ends are joined to a copper wi mounted on an electrically insulating disk *V*. Connecti leads (not shown) are brought out through holes in the li With this radial disposition of the heating elements, he conveyed to the liquid is widely dispersed and local ove heating avoided.

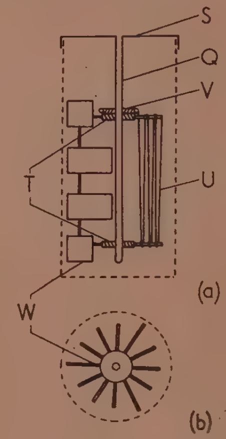


Fig. 2. The calorimeter heater and stirring fins

(*a*) Elevation: showing single heating element and set of fins.

(*b*) Plan: showing radial disposition.

Three sets of fins *W*, comprising copper foil strips soldere to copper wires, are mounted symmetrically around the dis as shown. The whole assembly is treated with sever applications of an insulating thermosetting lacquer (Bakeli Damarda Lacquer L3128) which is known to be unaffecte by any of the liquids to be investigated.

The jacket. This is an electrically heated metal surrou which is less cumbersome, and the temperature of which c be controlled with more facility than the water-jacket syste frequently employed. It consists of a brass tube (7 in. lon $2\frac{5}{16}$ in. internal diameter, $\frac{3}{32}$ in. walls) closed at the ends cessed brass plates of the same thickness, these being a ish-fit. The inside walls are chromium-plated and highly lished. Constantan wire, electrically insulated from the etal by thin lacquered asbestos paper, is wound on the tube form a heater, a spacing of 2 mm being allowed between rns. Layers of asbestos sheet wound over the heater and mented into position provide thermal lagging about $\frac{1}{4}$ in. ick. The end plates are provided with flat heaters with milar insulation, these being wound to the shape shown in g. 3 with the aid of a jig. The spacing between adjacent ns of wire is again 2 mm. The three cone-shaped Bakelite llars ($1\frac{3}{16}$ in. long), on which the calorimeter stands, are olted into position on the lower jacket plate before cementing e heater into position. Holes drilled in the top plate and rovided with insulating bushes allow the passage of thermo- ouple and calorimeter heater wires. The tube and plate eaters are connected in series, the power supply being either battery of 12 V accumulators, or, more conveniently, a.c. ains. In either case, the current is variable through a anually-operated rotary rheostat so as to afford jacket mperature control. No induction effects are noticeable ith the thermoelement when using a.c. mains.

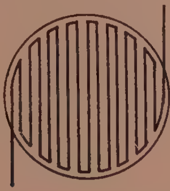


Fig. 3. Jacket end-plate heater winding

The uniformity of the temperature distribution over the ner surfaces of the jacket was checked under typical working onditions by comparative measurements with a number of ermocouples cemented to the walls at various points. hese tests showed that small temperature differences can xist between points on the surfaces, but the uncertainty in e temperature uniformity is small enough to warrant no irther consideration. Radiative heat exchanges between alorimeter and jacket are small, and are minimized by aintaining a high polish on the surfaces.

TEMPERATURE MEASUREMENTS

The temperature of the test liquid is measured with a ten- nction thermoelement accommodated in the central tube f the calorimeter, the e.m.f. being measured with a vernier otentiometer. The sensitivity is such that a change of 1 μV the output of the thermoelement, corresponding to a mperature change of about 0·002° C, produces a galvano- eter scale deflexion of approximately 1 mm.

Silk-covered constantan and enamelled copper wires of 0 s.w.g. were used to construct the series combination of ten lver-soldered junctions. Bared parts were insulated with ellac and the battery of thermocouples bound into a ompact, pencil-like bundle for insertion into the calorimeter ibe. The battery of reference junctions, constructed in the ame fashion, was sealed into a glass tube for insertion into Dewar vessel containing finely-divided ice and distilled ater at 0° C. The thermoelement, encased in a protective lass tube, was calibrated in a water bath against a multi- nction element which had been standardized at the National hysical Laboratory. A cubic equation was derived which tted the data, and used to interpolate between fixed points.

ELECTRICAL MEASUREMENTS

The circuit arrangement for the supply and measurement of the power input to the calorimeter is shown in Fig. 4. The 2 V battery E, comprising a number of large capacity accumulators in parallel, is in series with a standard oil-immersed 0·1 Ω resistor S and switch M. The latter is a spring-loaded rocker arm carrying three simple on-off mercury switches. This is preferable to an equivalent double-pole double-throw toggle switch, as the mercury contacts are less prone to disturbance from mechanical vibrations. When the rocker is in the "up" position, one mercury switch is "made" and permits the battery to discharge through the "dummy" resistor D, the resistance of which is approximately equal to that of the calorimeter heater R. Moving the rocker to the "down" position allows current to pass to the calorimeter heater and, simultaneously, starts an electromagnetically operated clock C (1/100 s) for recording the time of current flow. Inaccuracies in synchronizing the heating and timing are negligible; the timing is also sensibly independent of the tension of the clock spring. Since a practically constant load is maintained on the battery throughout an experiment, voltage changes on switching are avoided. To minimize Joule heating effects and consequent current drift, all connexions in the circuit are of heavy (16 s.w.g.) copper, except for the short lead-in wires through the jacket top plate to the calorimeter, which are of 20 s.w.g. The conflicting requirements of low Joule heating and small heat conducting paths, necessitates a compromise on the size of these wires.

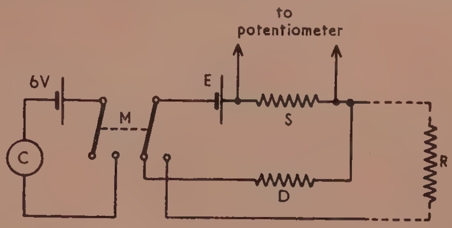


Fig. 4. Circuit arrangement for the supply and measurement of power to the calorimeter

Measurements of the variation with temperature of the resistance of the calorimeter heater, showed that this is so small that the resistance may be regarded as constant over the range 0 to 100° C; the value 0·5202 Ω measured at 20° C was taken, being easy to check from time to time. This constancy of resistance makes it possible to dispense with potential leads across the heater. With the usual notation, the electrical energy dissipated in the heater is calculated from the expression I^2Rt, the current I being found from the measurement of the p.d. across the known standard resistor. The conversion to gram-calories is made using $1\ \mathrm{cal}_{15^\circ} = 4{\cdot}186$ J. (In this connexion, see the recommendations of the Royal Society.(9))

Allowing for minor experimental errors, a typical heating period can be timed to better than 1 in 2500, whilst the heater current can be measured to approximately 1 in 5000.

CONTROL OF ADIABATIC CONDITIONS

The elimination of heat losses from the calorimeter is effected by regulation of the jacket and enclosure temperatures.

Jacket temperature. Ideally, this is at all times kept equal to the calorimeter temperature by variation of the current through the jacket heater. An indication of the temperature equality of the jacket and calorimeter is afforded by two opposed 40 s.w.g. copper/constantan thermocouples. One is cemented to the inner wall of the jacket, and the other to the outside vertical surface of the calorimeter. When connected to the mirror galvanometer the sensitivity is approximately 1 cm deflexion for a temperature difference of 0·1° C between jacket and calorimeter. Adequate continuous control of the jacket heater current is obtained with a series rotary rheostat operated by hand, and equality of temperature can be maintained during a run to approximately ±0·02° C.

No doubt a number of thermocouples distributed over the calorimeter and jacket surfaces would define their temperatures more precisely and allow closer control, but the single attachments suffice for the accuracy required. It is sometimes necessary for the temperature of the calorimeter and liquid to be maintained at a fairly steady value for long periods between specific heat determinations. The light beam reflected from the galvanometer is then made to actuate the relay in a photoelectric cell-amplifier-relay circuit, thus providing on-off control of the jacket current. The "hunting" with this device is too pronounced for close regulation and is not employed during actual experimental runs. To be fully automatic, and free from "hunting," the use of a thyratron in a phase-shift circuit effecting continuous current variation$^{(10)}$ would appear to be required.

Enclosure temperature. The enclosure is in effect an air bath, and provides a means of refrigerating the apparatus for measurements below room temperature, as well as eliminating thermal losses at all operating temperatures. Thus, by regulating its temperature so as always to approximate to that of the calorimeter, temperature gradients along the thermoelement and heater leads to the calorimeter are slight. Tendencies for heat exchange between the calorimeter and surroundings (external to the jacket), by conduction along these paths, are therefore negligible. Controlling the enclosure temperature to within a degree or two of that of the calorimeter is quite adequate. The necessity for exact equality would, in fact, be a disadvantage at temperatures lower than that of the room, for in order to get positive control of the jacket temperature, the enclosure must be slightly below the working temperature. Heating of the enclosure is accomplished by an open-mesh wire heater ($\simeq 500\ \Omega$) supported within the Perspex box. The power supply is from a.c. mains through a Variac transformer. Thermostatic control may be used, but in practice this is generally found unnecessary and occasional hand adjustment of the transformer suffices.

For working below room temperature, the enclosure is refrigerated by pumping acetone through a coil of copper tubing cooled by immersion in a Dewar flask of acetone and solid carbon dioxide, and thence through 20 ft of copper tubing mounted around the inside walls of the box. Rubber tubing connexions are taken out of the top of the box so as not to interfere with the stirring action. Temperature control is achieved either by working the box heater against the refrigerating action, or, more simply, by judicious regulation of the supply of carbon dioxide to the cooling flask. An electric fan serves to circulate the air in the enclosure at all temperatures.

An advantage gained by near-equality of jacket and enclosure temperatures is that a minimum demand is made on the jacket heater supply, which, in view of the dependence of heating on the square of the current, leads to easier precise control of the heaters' output.

CALIBRATION

Distilled water was used to calibrate the apparatus and determine the small variation with temperature of W, the water equivalent of the calorimeter and accessories. Th assumed values of the specific heat of water from 0–100° were those obtained by Osborne, Stimson and Ginnings.$^{(1}$ The values of W obtained are apparent values only, as the take into account the small errors introduced by uncertaintie in thermal control which are known to exist, particularly a elevated temperatures. Nevertheless, the W/temperature plo is reproducible to an accuracy consistent with specific hea determinations to better than ±0·5% and is the criterion o satisfactory performance of the apparatus. The averag experimental figure for W at about 20° C is 7·6 cal/°C wit a standard deviation of ±0·22 ($n = 12$). Obtained wit four-minute heating periods, this is typical of results through out the whole temperature range. Subsequent experiment showed that an optimum heating time is eight minutes (wate temperature rise approximately 2° C) and results in a usefu increase in precision. The eight-minute period was in genera adopted for specific heat measurements.

NOTES ON PROCEDURE

The procedure for specific heat determinations is straight forward, but accuracy and reproducibility require care an attention to detail.

The same volume of liquid (125 ml. ± 1 ml.) is used fo all experiments. This is weighed out into the calorimete and, if measurements are to commence below room tempera ture, is stored in a refrigerator overnight at a suitable tempera ture. In deciding the temperature of storage, allowance i made for the small rise in temperature of the contents whic occurs while assembling the apparatus. The preliminar assembling and adjustments to stable conditions usuall takes less than an hour.

During a heating period, the jacket temperature is made t follow that of the calorimeter, but the enclosure temperature if set at the mean of the temperature interval, need not b altered, provided liquid temperature rises of only 2 or 3° are being measured.

Temperature/time observations before and after a heatin period allow corrections to be made for occasional, small *constant* deviations from strict adiabaticity. No correction i needed for the heat of stirring, as this is imperceptible.

TYPICAL RESULTS

Typical results obtained from experiments on a whole mil and a cream in the temperature range 5 to 50° C are show in Fig. 5. These experiments show the increasing modifica tions to the curves with increasing fat content. Latent hea effects associated with melting of some of the fat constituent are evident at about 15 or 16° C in both curves, markedly s

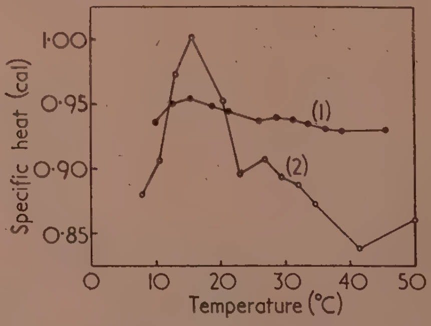


Fig. 5. Typical specific heat/temperature curves for
(1) whole raw milk, 4·3% fat
(2) thin cream, 21% fat

n the case of the cream. Similar but less noticeable effects ake place around 30° C.

Owing to the increased viscosity of the richer creams at emperatures much below 20° C, difficulties arise in adequate tirring, and this limitation throws some doubt on the results n these cases; other methods of determining the specific neat are then necessary. Nevertheless, temperature/time curves in these regions are of value.

Another application of the apparatus should be mentioned, and that is the determination of specific heat/time relationships at chosen temperatures. This is particularly relevant vith those dairy products, the behaviour of which is influenced o much by the temperature and time of holding.

ACKNOWLEDGEMENTS

The author is grateful to his colleagues of the Physics Department for useful discussions. Thanks are due to nembers of the Engineering Department of the Institute for he construction of some of the components, particularly Mr. E. G. Silver who machined the actual calorimeter; also Mr. P. G. Francis of the Chemistry Department, University of Reading, for assistance in calibrating the thermoelement.

REFERENCES

(1) Fleischmann, W. *J. Landwirtschaft*, **50**, p. 33 (1902).
(2) Hammer, B. W., and Johnson, A. R. *Iowa St. Coll. Agric. Mech. Arts, Res. Bull.* No. 14 (1913).
(3) Rishoi, A. H., and Sharp, P. F. *J. Dairy Sci.*, **21**, p. 399 (1938).
(4) White, W. P. *The Modern Calorimeter* (New York: Chemical Catalog Co., Inc., 1928).
(5) Sturtevant, J. M. *Physical Methods of Organic Chemistry*, Vol. I, Ch. X (Ed. A. Weissberger) (New York: Interscience Publishers Inc., 1945).
(6) Lipsett, S. G., Johnson, F. M. G., and Maass, O. *J. Amer. Chem. Soc.*, **49**, pp. 925, 1940 (1927).
(7) Sturtevant, J. M. *J. Phys. Chem.*, **45**, p. 127 (1941).
(8) Hunziker, O. F. *Condensed Milk and Milk Powder*, p. 27 (Published by the author, La Grange, Illinois, 1935).
(9) *The Unit of Heat*, issued by the Royal Society (1950).
(10) Strong, J. *Modern Physical Laboratory Practice*, 1st ed., p. 447 (London: Blackie and Son Ltd., 1938).
(11) Osborne, N. S., Stimson, H. F., and Ginnings, D. C. *J. Res. Nat. Bur. Stand.*, **23**, p. 197 (1939).

A compact monochromator employing rhombic, constant deviation prisms

By J. W. Gates, M.Sc., A.Inst.P., and S. P. Middleton, National Physical Laboratory, Teddington, Middlesex

[*Paper received* 11 *November*, 1954]

This instrument was designed to isolate narrow spectral bands from discharge lamps and continuous sources more efficiently than is possible by using filters. Two 60° rhombic prisms are used to secure high dispersion for small physical size: the form of the prisms makes for compactness. A brief analysis of the problem of deciding on the prism shape is given, and the properties of a number of prisms are stated. The total deviation produced by the two rhombic prisms is 240°, so that the entrance and exit directions cross near the region of the entrance and exit apertures. These apertures are formed in a rotating turret, by means of which alternative pairs of apertures may quickly be brought into use. The diameter of each pair of apertures is twice the diameter of the next smaller aperture in order to facilitate the repetition of photographic exposures. Methods of making suitable apertures of various sizes down to 50 μ and less are described elsewhere.(5)

ptical measurements with interferometers and other instruments frequently require a small monochromatic light source hich can be exchanged quickly for a source of another avelength. Usually more than one wavelength is emitted y the discharge lamp and the problem is to filter out the nwanted parts of the spectrum. Filters of high efficiency ave been devised for a few spectral lines, but usually a filter hich passes a high proportion of light of the wanted wavength will also permit appreciable quantities of unwanted avelengths to pass. This is particularly true of the colour lters which pass bands at the violet end of the visible pectrum. It is possible, on the other hand, to construct mple monochromators which pass as much light as most f the best filters, and yet cut out the unwanted wavelengths uch more effectively. Moreover, such instruments can be ade adjustable for use at any wavelength. The effective ource available from a monochromator is, however, estricted in size, and the maximum convergence of light at e source is limited by the relative aperture of the monoromator. In cases where the source required is small, and e system following the monochromator is of a smaller lative aperture than the monochromator, there is no limitation. Such cases arise in interferometry, and in the testing of optical systems by means of "star images." In these cases the instruments which have been constructed have proved to be ideal.

OPTICAL DESIGN

The monochromator was designed in the first place to be mounted as an integral part of a small interferometer. The exit aperture, which forms the light source for the interferometer, was therefore required to be one of six interchangeable circular holes of diameters 2·0, 1·0, 0·50, 0·25, 0·13, 0·063 mm. These apertures of fixed size provide a means of repeating photographic exposures without the need to re-determine the exposure time. Each aperture has four times the area of the next smaller. For convenience it was decided to mount these apertures on a rotating turret and to arrange that the entrance aperture of the monochromator corresponding to each exit aperture should also be mounted on a turret and swing in simultaneously. This is most easily done by mounting both sets of apertures on the *same* turret, and the properties of the various possible optical systems were examined with this end in view.

The relative aperture of the optical system was required to be $f/5$, and the linear dispersion at the exit aperture was to be sufficient to isolate the mercury wavelength 546 mμ from the adjacent wavelength 577 mμ, using 1 mm apertures. These lines are the closest of the emission lines of any single lamp used in interferometry. Extra dense flint glass was selected as material for the prisms from a consideration of the conflicting claims of high dispersion and a reasonable transmission at the violet end of the spectrum. A calculation of the focal length of the lenses required to produce the necessary linear dispersion at the exit aperture, using one 60° prism of this glass, indicated that the lenses would have to be about 180 mm in focal length.(1) Such an instrument would have been rather too bulky and heavy, but by using two 60° prisms or the equivalent, the focal lengths can be halved, and the instrument can be scaled down almost in proportion. Some components are reduced in weight to one-eighth, and the two prisms together weigh only a quarter as much as the single prism would have done. Accordingly the lenses were specified as achromatic doublets of 90 mm focal length and a working aperture ratio of $f/5$.

The next step was to consider the possible forms of the two prisms. When the entrance and exit directions are fixed it is convenient to use constant deviation prisms. Many shapes are possible, though forms other than those of Pellin and Broca(2) with 90° constant deviation, and Littrow(3) with 180° constant deviation, seem to be very rare. In general, however, any prism can be used as a constant deviation prism if the ray path is such that two refractions and a reflexion occur, and the dispersion occurring at the two refractions is additive. When the reflexion occurs internally and takes place between the two refractions, there will be only three external faces of the prism involved. Consequently, any triangular prism, except an equilateral prism, can be used as a constant deviation prism, though the dispersion produced will not always be the same, and may even be zero. This problem has been studied by Blakesley.(4) Often it is convenient to truncate one or more angles of the triangle to save material, as in the case of the Pellin–Broca prism, which is essentially a 90°–75°–15° triangular prism with the 15° angle truncated. In all cases the faces formed by truncation do not need to be polished. Some constant deviation prisms with the same dispersion as a 60° prism are shown in Fig. 1. The maximum amount of truncation has been performed and the resulting base area is compared in each case with a 60° prism of the same aperture. All the prisms are truncated triangular prisms except the prisms with 60° and 120° deviation. The former is not truncated, and the latter is rhombic, but the two prisms have the same base area, which is considerably less than the Pellin–Broca form. These two are the smallest of the whole range covered by the examples given, with the exception of the Littrow prism. Unfortunately, it is difficult to employ two Littrow prisms in series, and the choice therefore lies between the two forms with 60° and 120° deviation respectively. The second of these, the rhombic prism, gives a total deviation of 240° for the two prisms in series, which causes the entrance and exit directions to cross and permits the entrance and exit apertures to be brought close together. The rhombic prism is also a little more compact than the other and the quality of optical work required is somewhat less because of the smaller angle of incidence at the reflecting face. These advantages outweigh the disadvantage of having to metallize the reflecting face, and the rhombic prism was consequently chosen. After polishing, the refracting faces were coated with magnesium fluoride to reduce reflexions and to protect the surfaces, and the unpolished surfaces were painted with a black paint of high refractive index.

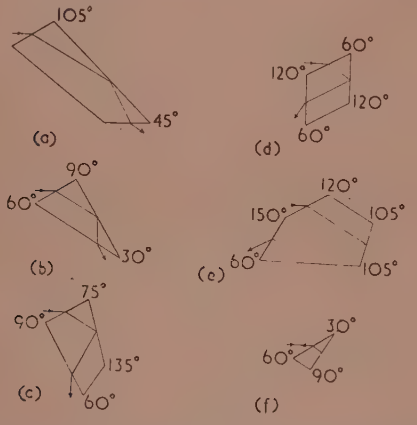


Fig. 1. Constant deviation prisms with the same aperture and dispersion as a 60° prism having a minimum base area of 1·00 (reference)

(*a*) 30° deviation, area 5·89
(*b*) 60° deviation, area 2·00
(*c*) 90° deviation, area 2·61 (Pellin–Broca prism)
(*d*) 120° deviation, area 2·00
(*e*) 150° deviation, area 4·73
(*f*) 180° deviation, area 0·50 (Littrow prism)

MECHANICAL DESIGN

The layout of the instrument is shown in Fig. 2. The optical parts are symmetrical: each prism is mounted on a table which rotates about a vertical axis lying in the centre of the outer refracting face of the prism, and the tables are linked so that they rotate in opposite directions through the same angle. The rotation is controlled by a tangent screw which carries a wavelength scale and acts against a projection on the underside of one of the prism tables; the motion is opposed by a flat spring. The lenses are carried in threaded cells and are locked after focusing. The frame of the instrument, and most of the metal parts, are made of aluminium alloy, painted black to reduce the reflexion of stray light. The rotating turret is made of free-cutting brass, black-bronzed, and the pinholes and slits, used as exit and entrance

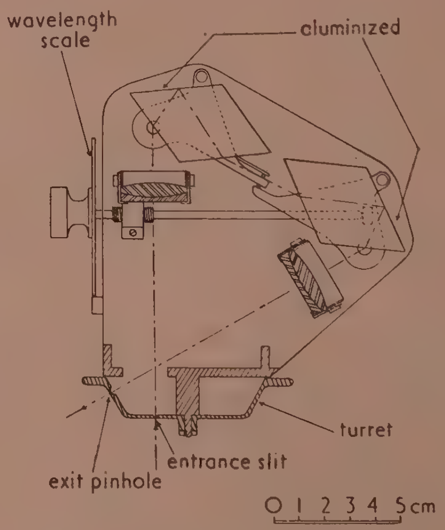


Fig. 2. Plan view of monochromator

tures respectively, are formed directly in the material of turret by the methods described in another paper.⁽⁵⁾ re are six sets of apertures, of the sizes already given, ned in the turret at 60° intervals. The six angular positions he turret are set by a ball and V-groove detent. The exit pinholes are in the conical face of the turret and are made in the form of a conical hole with a knife-edge where the hole meets the outer conical face of the turret. The slits are formed in the circular face of the turret, and also have knife-edges. Each slit has the same width as the corresponding pinhole. The slits are curved and were formed by rotating the turret on its own axis of rotation through a small angle while the cutter was at work. The radius of the slit could be chosen to eliminate the curvature of the image on the exit slit caused by the prisms, but in the present case, where the exit aperture is a hole, the correction is unnecessary. Curved slits are used for the entrance apertures for convenience in making the turret, and to prevent slight misalinements of the optical parts causing the wanted image at the exit aperture to be cut off. Under the baseplate a mounting boss is provided for attaching the monochromator to ordinary optical bench fittings. A light stand is also provided so that the instrument can be used on a flat bench. The complete monochromator, without stand, weighs only 680 g (1 lb 8 oz), and is shown, with the cover removed, in Fig. 4.

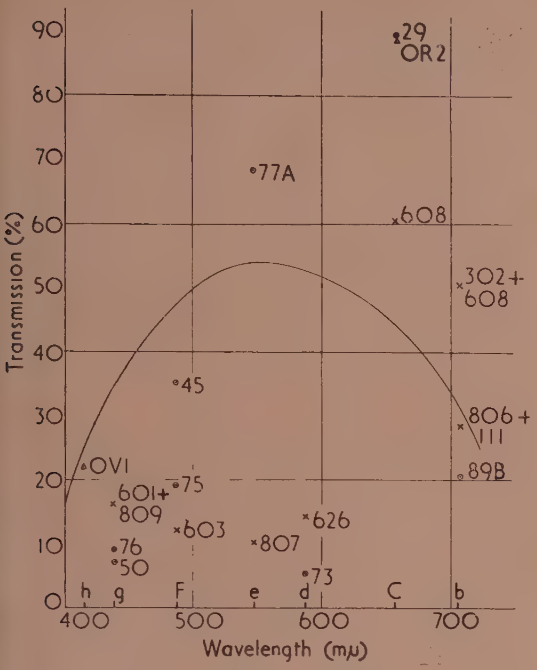
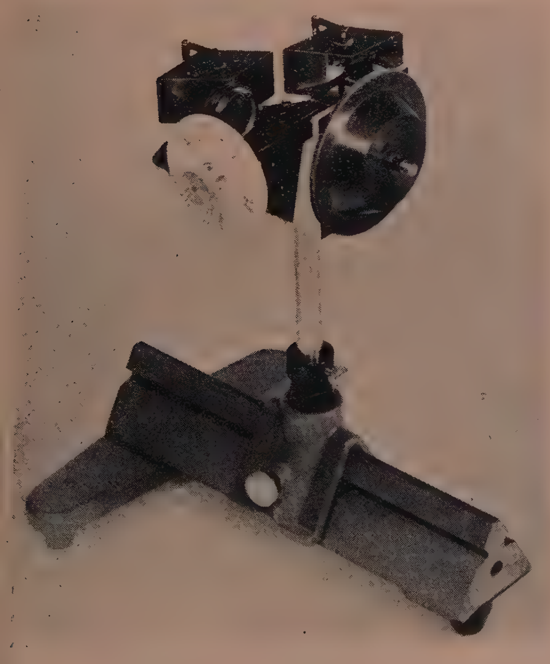


Fig. 3. Spectral transmission of monochromator

he transmissions of the best glass and gelatine filters for standard spectral lines are shown for comparison.

= Kodak Wratten filters; × = Ilford filters; △ = Chance glass.



ig. 4. Monochromator, without cover, mounted on an optical bench

PERFORMANCE

A comparison of the transmission of the monochromator with the transmission of spectral filters was of interest. The curve, Fig. 3, was obtained from measurements with a number of monochromatic light sources. Some of the filters used for isolating the standard spectral lines used in optical work are shown for comparison. It must be remembered that in nearly all cases the filters are less efficient in removing unwanted wavelengths than the monochromator, and that filters for isolating non-standard spectral lines are often less efficient than the filters shown. Even without taking this into account, however, the monochromator has a higher transmission than most of the filters. A similar investigation of the transmission of filters and monochromators is given in a National Bureau of Standards circular.⁽⁶⁾

ACKNOWLEDGEMENTS

The optical parts of the prototype were made by the staff of the Light Division Glass-working Shop, and the instrument was constructed by Mr. P. Kendall, of the Light Division Instrument Workshop. A second instrument was made by Mr. J. M. Crowley, also of the Light Division Instrument Workshop.

The work described has been carried out as part of the research programme of the National Physical Laboratory and this paper is published by permission of the Director of the Laboratory.

REFERENCES

(1) Sawyer, R. A. *Experimental Spectroscopy*, pp. 50–88 (New York: Prentice-Hall, Inc., 1951).

(2) Pellin, P., and Broca, A. *Séanc. Soc. Franç. Phys.*, **1**, pp. 24–9 (1899); *J. Phys. Théor. Appl.*, **8**, pp. 314–19 (1899).

(3) Littrow, O. von. *S.B. Akad. Wiss. Wien*, II, **47**, pp. 26–32 (1863). See also Kayser, H. *Handbuch der Spectroscopie*, Vol. I, pp. 374–94 (Leipzig: S. Hirzel, 1900).

(4) Blakesley, T. H. *Proc. Optical Convention (London)*, 1905, pp. 54–60 (London: Williams and Norgate, 1905).

(5) Middleton, S. P. *J. Sci. Instrum.* To be published.

(6) *Spectrophotometry*, Circular 484, pp. 7–10 and 31–5 (Washington: National Bureau of Standards, 1949).

Laboratory and workshop notes

A simple reflexion-transmission stage for an electron microscope

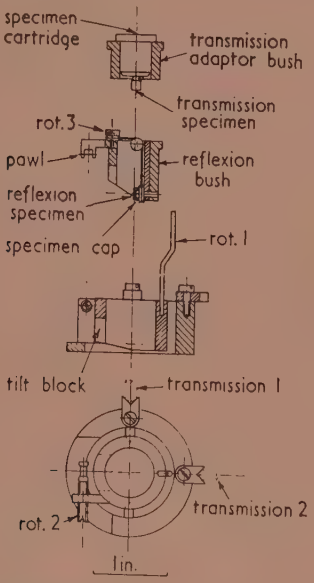
By K. Amboss, B.Sc., The British Paper and Board Industry Research Association, Kenley, Surrey

[*Note received* 9 *September*, 1954]

For reflexion electron microscopy it is essential to have a stage which gives the specimen five degrees of freedom. These are two translations, in and perpendicular to the plane of incidence; a rotation of the plane in which the specimen lies; and two further rotations of limited extent, one about a horizontal axis and the other about the vertical axis which defines the centre of the objective lens. If these axes pass through the centre of the specimen support, movements of the specimen will be largely independent of each other. This note describes a stage designed to meet these requirements suitable for the type E.M.3 electron microscope by Metropolitan-Vickers Electrical Co. Ltd.

The three existing stage controls outside the vacuum have been utilized, following the practice of Menter,* and permit the stage to be moved in two orthogonal directions in the horizontal plane (trans. 1 and 2) and allow it to be tilted about a horizontal axis lying parallel to one of the directions of translation (rot. 1). (This last control is used in transmission for stereophotography and in reflexion for alteration of the angle of incidence of the electrons.) The two further degrees of freedom enumerated above can, after a little practice, be adjusted when the specimen is first placed in the instrument and therefore need not be controlled from outside the vacuum.

In construction the new stage is similar to the one supplied by the makers. The tilting block, however, swings about an axis which is located 5 mm above the top objective pole face, at which distance the centre of the specimen is situated; it permits a tilt from −2° to +14°. The central portion of the block is bored out to take either reflexion or transmission specimen bushes (see figure). A spindle runs horizontally and parallel to the axis of tilt through a screwed hole in lug welded to the tilt block. A pawl on the reflexion bu engages with a groove on the spindle and thus provides t drive for the rotation about the lens axis (rot. 2). A mov ment of ±15° is possible.



Reflexion-transmission stage for electron microscope

The specimen sits on a small cap which fits over a pull situated at the bottom of the reflexion bush. The pulley a therefore the specimen are rotated (rot. 3)—through ±270° by means of a wire drive passing over idler pulleys at t top of the bush on to a small capstan. Part of the bush a tilt block are cut away to permit observation of the specim during operation of the microscope, the door of the specim chamber being replaced by a plate of X-ray proof glass.

For transmission work, the specimen cartridge supplied the makers is put into an adaptor bush which fits into t tilt block and brings the specimen to the required distan from the top pole face of the objective.

In either mode of operation an area about 3 mm squa may be scanned.

---

* Menter, J. W. *J. Inst. Metals*, **81**, p. 163 (1952).

A laboratory gas-flow control device

By R. A. Hall, M.Sc., Imperial Chemical Industries Ltd., Nobel Division, Stevenston, Ayrshire.

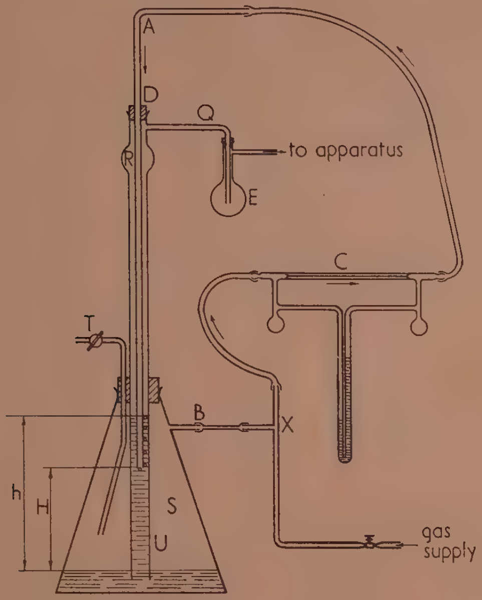
[*Note first received* 24 *September, and in final form* 7 *October*, 1954]

Gas flow control devices based on the principle of maintaini a constant pressure difference across a capillary tube ha been described.(1, 2, 3) The operation of these devices, ho ever, necessitates venting some of the gas out of the apparat This procedure may be undesirable in cases where the gas in short supply, or unpleasant in nature. The appara described was designed to work without venting any gas further advantage is that the flow remains constant irrespect of fluctuations (within wide limits) either in the supply l or in the system to which the gas is being supplied.

The operation of the apparatus is best understood reference to the diagram. Gas from the generator is divid at *X*. One branch leads to the closed space *S* and thus for the fluid contained in the Buchner flask up the central tube to a height *h* corresponding to the difference in pressu between that of the incoming gas and the pressure in t space *R*. The latter is the pressure in the reaction appara since it is connected directly to it *via* *Q*. The gas flow its proceeds through the other branch from *X*, through t capillary *C* and thence as shown by the arrows down t tube *A*, finally bubbling up and out to the reaction appara through *Q*. The tube *A* is made a close sliding fit in t rubber bung *D*, and the flow rate can be adjusted by slidi *A* up or down.

The flow control operates as follows: consider first t effect of any change of pressure in the apparatus to wh the gas is being delivered. Any such increase (or decrea of pressure will cause a corresponding decrease (or increa in *h*, so that the pressure P_2 at the capillary exit will not affected; hence the gas flow rate will not change. Second consider the effect of changes in the pressure P_1 of the supply. Any such increase or decrease will result in a c responding increase or decrease in *h*, and hence in P_2 so t $(P_1 - P_2)$ does not change. Thus at all times $(P_1 -$ remains constant, and, subject to the following proviso, flow rate will also remain constant.

The above argument would be strictly true if the level of liquid in the flask remained fixed. In fact, however, this el will vary slightly and inversely with h, in about the ne ratio as the *effective* cross-sectional area of liquid in central tube to the area of liquid in the flask. The ctive surface area of the liquid in the central tube is ually very small when the apparatus is in operation, being fact the area of cross-section of the annular space R, less amount depending on the rate at which gas is bubbling through the liquid. It is easily shown that the percentage iation in flow rate with the height h of the liquid in the tral tube is given by the expression



Gas flow control device

$$100Z(h - h^0)/H$$

ere

^{0} = the original height of the liquid in the central tube;
Z = area of liquid surface in central tube/area of liquid surface in flask.

As an example, using an inner glass tube of 0·25 in. outside meter and an outer glass tube of 0·625 in. internal diameter, h a Buchner flask of 6 in. base gives Z a value of about 01, so that the above expression becomes $(h - h^0)/H$ to a se approximation. It is desirable to make h^0 approximately equal to $2H$ (by suitable choice of liquid and control supply pressure at the start). An apparatus of the above nensions would then accommodate a 50% variation in pressure difference between supply and outlet lines, with ariation in the volume rate of flow of only 1%.

The closed space S should be first flushed out with the gas ng used, *via* B and the tap T, in order to prevent slow fusion of air or other gas from S into the gas stream at X. necessary the Buchner flask can be replaced by a vessel cially shaped to reduce the volume S, in order to facilitate s operation.

The catch-bulb E is fitted to guard against any sudden and expected pressure variations either in the supply or exit es, which might be large enough to force the liquid up l over into the exit arm Q.

The actual dimensions of the apparatus will depend upon gas being used, the flow rate, and the choice of liquid. It is convenient to use the same liquid in the flowmeter as in the apparatus since H is then equal to the difference in the flowmeter levels.

REFERENCES

(1) Oberfell, G. G., and Mase, R. P. *Industr. Engng Chem.*, **11**, p. 294 (1919).
(2) James, D. H., and Phillips, C. S. G. *J. Sci. Instrum.*, **29**, p. 362 (1952).
(3) Dodd, R. E., and Robinson, P. L. *Experimental Inorganic Chemistry*, p. 132 (London: Elsevier Publishing Co. Inc., 1954).

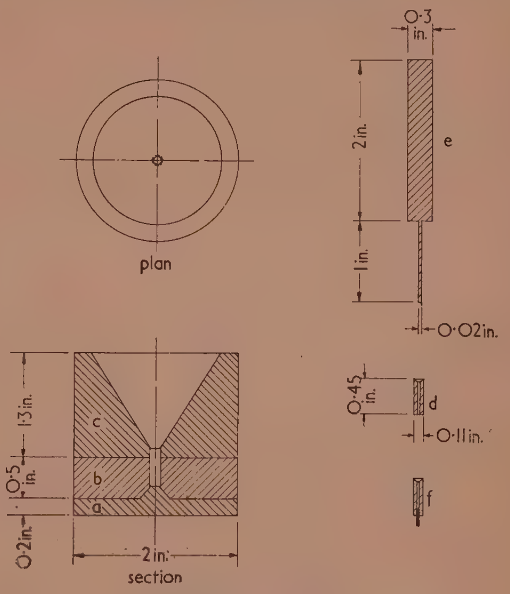
Simple extrusion press for preparation of specimens of optimum thickness for X-ray diffraction powder photographs

By M. Kossenberg, Ph.D., Coal Research Section,
Commonwealth Scientific and Industrial Research
Organization, New South Wales, Australia

[*Note received* 9 *June*, 1954]

The use of any binder in the preparation of specimens for powder photographs is often inadvisable, as haloes produced by the binder can interfere with the pattern produced by the substance under investigation. It is also desirable to produce specimens of optimum thickness in order to ensure the maximum diffraction effect.

The cylindrical extrusion press, shown in the figure, satisfies these two requirements. The press itself is composed of three separate parts, a, b and c, which can be assembled one on another. The part c is a block with a funnel-shaped cavity and a specimen holder d fits in the central opening in b and c. Several specimen holders of different internal diameter can be fitted and to any specimen holder there is a corresponding punch e.



Extrusion press

The preparation of specimens is accomplished in the following way. The three parts, a, b and c, are assembled and the specimen holder placed in position; some of the powdered specimen is placed in the funnel and, with the punch e, pressed into the specimen holder until it is about half full. Part a is then removed, and using the punch the specimen is pressed out about 3 mm. Part *c* is removed and the specimen holder with its pencil of specimens (see *f*), is carefully removed. The specimen holder fits directly into the rotating support in a powder camera.

It should be stressed that the inside wall of the specimen holder should be polished, otherwise appreciable friction occurs between particles of powder and the walls and greater pressure is required in the extrusion. The use of ordinary machine oil facilitates the extrusion of hard materials. The press is in satisfactory use for the preparation of coal specimens in this laboratory in connexion with the coal research programme of the C.S.I.R.O.

An optical system for use in conjunction with glass spiral pressure gauges

By V. C. Ewing, Ph.D.,* Queen's University, Belfast

[*Note received* 5 *November*, 1954]

Yorke† has described an optical lever to record the differential pressure between the inner and outer surfaces of a thin-walled glass spiral. Owing to the fact that the glass spiral is bent at a sharp angle to the main tube so that the mirror can be mounted axially, the system is fragile and difficult to make. The method described below, by eliminating the mirror and the need to bend the thin-wall tubing after removal of the spiral from the mandrel, is easier and gives a system that is at least as sensitive and more robust.

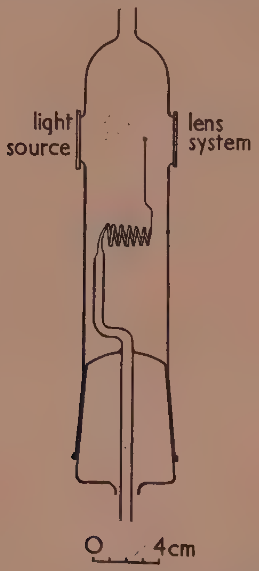


Fig. 1. Spiral gauge mounting

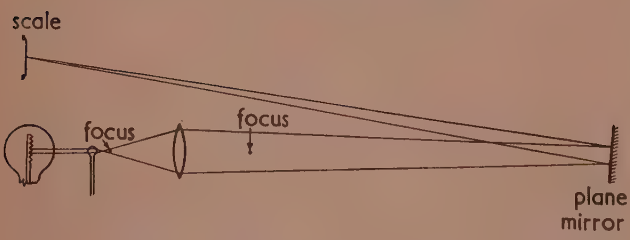


Fig. 2. Optical system used in conjunction with the spiral gauge

A small bead of glass approximately 1 mm in diameter formed at the end of a 5 cm pointer. The pointer is attach to the end of the spiral at right angles to the axis of the c (Fig. 1). When illuminated by a line filament, the be forms a greatly reduced image of the source. This ima of the light source and the bead itself are magnified by biconvex lens of 3·8 cm focal length (Fig. 2). At a distan of 6 m from the lens a sharp bright image of the filame 1·5 mm in width is produced, surrounded by the magnifi umbra of the bead itself which appears as a darker shad against the penumbra. A deflexion of 16 cm for 1 c mercury pressure difference was obtained using a gau which rotated through 120° for one atmosphere pressu difference.

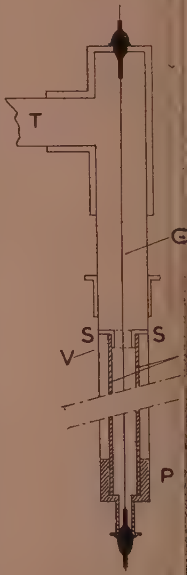
A coaxial line suitable for low-temperature work

By D. Bijl, M.A., Ph.D., and H. Pullan, M.A., D.Phil.,
Clarendon Laboratory, Oxford

[*Note received* 29 *September*, 1954]

In the course of experiments with a radio-frequency oscillat of which the tank circuit was placed in a cryostat, a noticeab effect of the level of the cooling liquid on the frequency w observed. This could only be caused by changes in t temperature distribution (and therefore in the dimension of the coaxial line which connected the tank circuit with t cap of the cryostat and the other parts of the oscillator. Evaporation of the cooling liquid caused a gradual drop in level which made itself felt as a regular drift of the frequency. The following design of coaxial line eliminated this trouble and may be useful for other workers in this field.

The principle is sketched in the figure. *V* is a thin-walled German silver tube (diameter 1·2 cm, length 30 cm) which is closed at the lower end by a copper plug *P*. A copper tube *R* (length 22 cm, outer diameter 0·8 cm, wall thickness 0·16 cm) is soldered to *P* and is prevented from touching the German silver tube by a Perspex ring *S*. A poor heat contact between *R* and *V* is essential. The inner conductor is a thin-walled German silver capillary *G* (diameter 0·05 cm) which is supported by Kovar seals at both ends. The capacity between the inner and outer conductors of this coaxial line consists practically of the capacity between *R* and *G*. The whole system can be evacuated through the side tube *T* (in order to reduce the heat contact between *V* and *G*) and is mounted vertically i a bush on the cap of the cryostat.



Coaxial line suit able for low temperature work

During experiments the top end of the coaxial line is room temperature and the lower end is immersed in th cooling liquid. Because of the high heat conductivity of th copper the tube *R* is virtually at the low temperature inde pendent of the level of the liquid. Consequently the capacit between *S* and *R* remains practically constant. With th arrangement variations of more than 10 cm in the level the liquid hydrogen in the cryostat altered the capacity the coaxial line (14 pF) by less than 0·002 pF, which wa adequate.

---

* Now at Physical Chemistry Laboratory, University of Oxford.
† Yorke, S. G. *J. Sci. Instrum.*, **22**, p. 196 (1945).

Correspondence

Modifications to the omnidirectional ionization anemometer

n the original instrument described by Lovelock and Vasilewska,(1) the ionizing electrode was a sphere plated with olonium. The collecting electrode consisted of three rings, ach 8 cm in diameter, joined together so that they were oncentric and mutually at right angles. Concentric with his collecting electrode was a shielding cage 9 cm in liameter, also consisting of three mutually perpendicular rings.

The short half-life of polonium (less than six months) is a lisadvantage, and a more serious difficulty arising from the se of this element is the tendency for particles of it to be lispersed and become airborne. Polonium is now known to e highly toxic, so that, unless its dispersion can be avoided, ts use in the construction of the anemometer is undesirable. oth these difficulties have been overcome by using as the onizing agent radium, which is sandwiched between thin ilms of gold backed with a stiff silver foil. Thus any radon roduced is retained. Other members of the series which vill occur in time are also retained, so that such radium foil enerally emits copious β- and γ-radiation and also has a eterogeneous α-emission.

The ionizing electrode is made by covering a half-inch ball-earing with the radium-gold foil. Pieces of foil in the shape f thick-waisted figures of eight are cut by means of a special ool, and the shaped pieces then moulded, by pressing them nto a female hemisphere, so as to form interlocking shapes imilar to those from which a tennis ball is made. Two of he shaped and pressed pieces of foil are then fitted around he ball-bearing and secured by means of Bostik. The ball-earing is previously fully tempered to allow drilling and apping for the supporting rod, which is $\frac{1}{8}$ in. in diameter. The size and shape of the tool used for cutting the foil were etermined by trial and error and the radius of the hemisphere vas made 0·260 in. The shaping and pressing must be done vith much skill and care, otherwise the active layer will be xposed or removed; the joint between the two pieces of foil nust be good.

In the modified instrument the collecting electrode consists f three rings as before, but of 10 cm diameter, and there ave been added three stubs which help to make the electric ield more nearly such as would be obtained from concentric pheres. The addition of these stubs, at the suggestion of Mr. M. J. Hickman of the National Physical Laboratory, as reduced the difference in the indicator readings due to rientation to 5%.

Experience showed that the electrical shielding needed to e improved, and in the modified instrument the collecting lectrode is now surrounded by a wire mesh sphere 15 cm in liameter. The size of the mesh is a compromise between that eeded for perfect shielding and that which would offer no bstruction to air movement. The average distance between djacent wires is about 1·5 cm.

A photograph of the complete instrument is shown as ig. 1.

A consequence of the new construction is that the calibra-ion curve deviates rather more from a straight line than did hat of the original instrument. This effect is due to the ormation of appreciable numbers of ions outside the electrode ystem by β- and γ-radiation, and the deviation is yet more ronounced if the shield is made smaller in diameter.

A typical calibration curve is shown in Fig. 2. (The calibration at speeds of 50 ft/min upwards was carried out by the Physics Division, National Physical Laboratory.)

A reading of 1½% of the full scale is obtained with an air

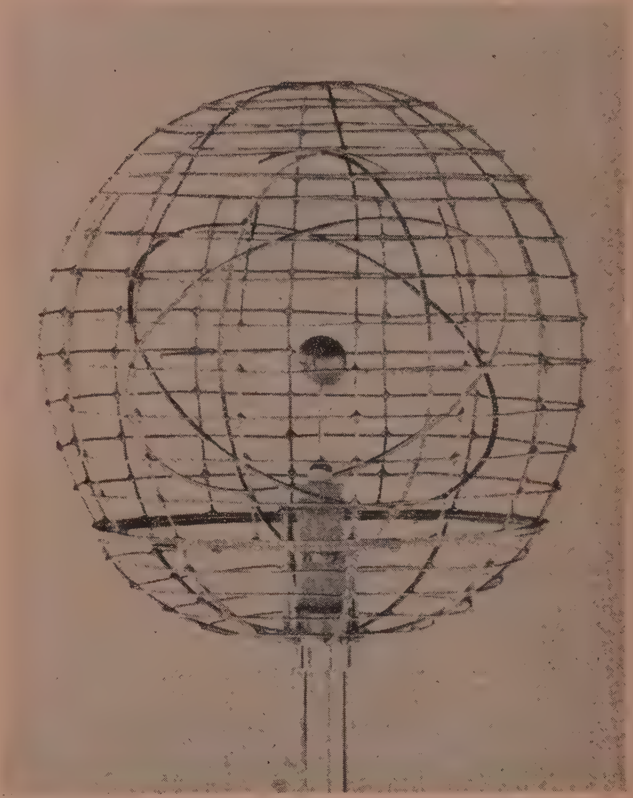


Fig. 1. The modified anemometer

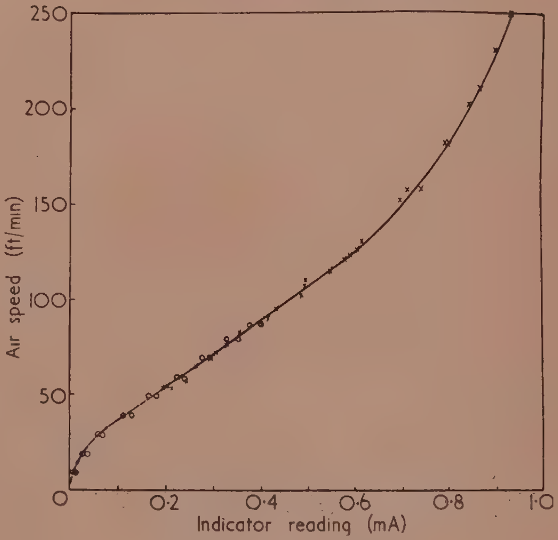


Fig. 2. The calibration

Anemometer potential 85 V.

X = calibration in 15 in. tunnel; O = calibration in 8 in. tunnel.

speed of 10 ft/min. The maximum sensitivity occurs at speeds between 30 and 120 ft/min, and within that range the meter reading changes by about 6% of full scale for a change of 10 ft/min, whereas at speeds of about 300 ft/min a shift of 10 ft/min changes the meter reading by 1½% of full scale. A lower meter range is provided which gives full scale deflexion with a speed of about 100 ft/min, and this has been found most useful for the measurement of air speeds in closed rooms.

When the radium-gold foil in the ionizing electrode has been shaped satisfactorily, so that its active layer is uniform in thickness, an almost circular polar diagram is obtained for the response to a wind of constant speed from varying directions in the plane perpendicular to the handle of the instrument. For other planes the departures from this polar diagram are negligible so long as the angle made with the handle is greater than 30°. At smaller angles the effects of supports and of the handle are felt and aerodynamic shielding causes a fall in sensitivity, the amount of the fall depending on the size of the support.

Ordinary polythene-insulated cables when flexed or strained can produce instantaneous voltages of the order of 40 mV in a 200 MΩ resistor. Hence, to connect the anemometer to its amplifier, a special "non-microphonic" cable with three conductors (including shield) is necessary. A cable such as Telcon type K16/GMYM gives excellent results. The foil used in this instrument has a radium density of 100 μg/in.^{2}. Hence the total amount used on the sphere is between 70 and 80 μg. This amount of radium causes an ion current in still air of about 7×10^{-9} A, and in order to have adequate sensitivity the amplifier must be capable of measuring a current change of the order of 10^{-11} A.

Amplifiers which measure currents of the order of 10^{-11} A from a high impedance source are now commonplace. A simple circuit was described by Lovelock and Wasilewska,(1) and a more stable circuit, based on one first described by Scroggie,(2) has been illustrated by Welman and Lovelock.(3)

Sensitivity and zero controls are provided in order to allow adjustments for changes in parameters which affect the scale of the calibration curve, e.g. the amount of radioactive material present, small changes in applied potential difference, and normal changes in ambient air conditions.

When the original calibration is made the sensitivity control is set at a convenient, but otherwise arbitrary, position. For subsequent checking of the calibration the anemometer should be placed in a still-air enclosure with internal dimensions of not less than 18 in., and the amplifier set to zero. The potential difference across the electrodes is removed, thus reducing the ion-current very nearly to zero, and the sensitivity control is then so adjusted as to give the same meter reading as was obtained in the same way during the original calibration.

Owing to the fact that the outer shield is necessarily in the form of a mesh, and the shielding therefore not perfect, the effect of enclosing the anemometer in a metal case is to reduce the ion-current slightly. In enclosures of 18 in. or greater internal dimensions this effect is negligible, but with a much smaller enclosure it is necessary to set the meter not at zero but at a small positive value determined during the original calibration, and applicable only to an enclosure of the size used. An insulated enclosure may hold a static charge, and should not, therefore, be used.

The radiation hazards of the instrument here described, though small with proper usage, are not negligible as in the model in which polonium was used. The measured β- and γ-radiation dosage at the normal holding position of one foot from the active sphere is of the order of 20 mr/h. Taking the permitted dosage as 1·5 rep per week, this means that an operator can handle the instrument continuously durin normal working hours provided that no part of him is les than 1 ft from the radiating source, but care is necessary Since the radon is entirely retained, together with all othe elements of the disintegration series, there is no danger o ingesting or inhaling radioactive substances unless the foil i scratched or the outside gold film broken.

The writer is indebted to Dr. J. E. Lovelock for valuabl suggestions; to Mr. M. J. Hickman, of the National Physica Laboratory, for his help and criticism; to his colleague, Mr F. E. Smith, who constructed various models of the trans ducer; to Dr. T. Bedford, Director of the Environmenta Hygiene Research Unit, for encouragement and criticism and to Isotope Developments, Ltd., who manufactured the present model of the anemometer.

London School of Hygiene and Tropical Medicine,
Gower Street,
London, W.C.1.

W. L. **Welman**

REFERENCES

(1) Lovelock, J. E., and Wasilewska, E. M. *J. Sci Instrum.*, **26**, p. 367 (1949).
(2) Scroggie, M. G. *Wireless Wld*, **58**, p. 14 (1952).
(3) Welman, W. L., and Lovelock, J. E. *J. Instn Heat Vent. Engrs*, **22**, p. 421 (1955).

A versatile top terminal equipment for an electrostatic accelerator

In an investigation into the voltage performance of the 4 MeV electrostatic generator in this laboratory, it was found that there was a discrepancy between the voltage measurements using a generating voltmeter and those deduced from the measurements of known nuclear resonances. From a detailed analysis of the branch currents, both at the terminal and earthed end of the generator, this discrepancy can be understood, and an estimate of the currents flowing to the accelerator tube walls can be made. This letter describes some extensions to the telemetering equipment* which were used to analyse the current balance at the high-voltage terminal.

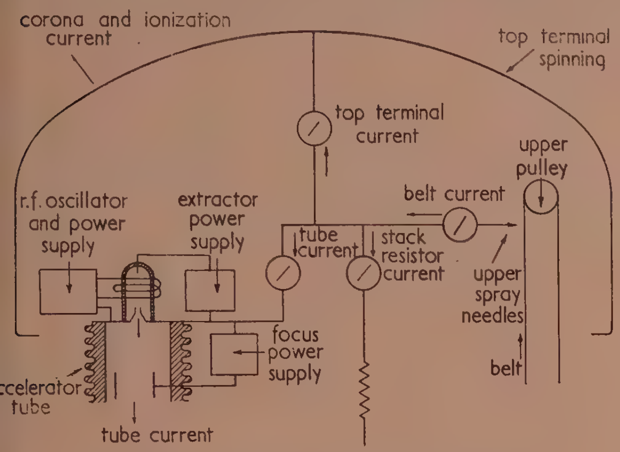
The general arrangement used for measuring some of the principal currents is shown in the figure. This outlines a circuit to measure the current leaving the belt at the to terminal, and the components of it which return to eartl *via* the stack resistors, as accelerator tube current, and as ga current from the top terminal spinning. The accelerator tub current measured is the total conventional current whicl leaves the ion source envelope, the top plate of the accelerato tube and the focus electrode, and passes to points lowe down the tube. It is not affected by currents flowing in the ion source oscillator and the various power supply circuits as these are purely internal.

In order to make the measurements, various portions o the equipment which had previously been directly connecte had to be insulated from one another. It was found mos convenient to have the "earthy" connexions of all the powe supplies and of the control and measuring circuits connecte directly to the accelerator tube. The top terminal spinnin could not readily be insulated from its base plate, so thes two elements were left in electrical contact, and insulatio as introduced between the base plate and the framework hich carried all the power supplies and other circuits. The amework was connected to the accelerator tube. Insulation the spray needles and the top end of the stack resistance ain was straightforward.

---

* Millar, B. *Electronic Engng*, **25**, pp. 446, 506 (1953).

The telemetering system was originally designed for dicating the operating conditions of the ion source and has en described elsewhere. Briefly, it is a five-channel system ing pulse time modulation of a light beam to transmit ormation from the high-voltage electrode to the base of the nerator. The indication is by the positions of pulses on e traces on the face of a cathode-ray tube. To permit easurement of the generator and accelerator tube para-eters as well as those of the ion source, the input circuits the telemeter transmitter were modified so that three of e five channels could each be switched by the control stem to indicate any one of five currents, so that up to venteen parameters could be remotely metered.



Arrangement of metering circuits of top terminal equipment for an electrostatic accelerator

Input signals to the telemeter transmitter must be applied currents in coils on peaking transformers requiring ampere turns for full modulation of any channel. It was t considered practicable to wind coils with more than about 00 turns, which gives full modulation for an input of 5 mA, but the new application required full modulation by rrents of the order of 100 μA. Resistors were therefore nnected in series with the circuits at the metering points own in the figure, and the end points of all the resistors re connected to the grids of cathode follower valves. To easure any current, relays were used to connect the appro-ate pair of cathode follower output points to the input nnexions of one of the telemeter transmitter coils. sistance-capacitance low pass filters were inserted between ends of the series resistors and the grids of the cathode lowers to smooth out rapid variations in the currents, and rge protection was provided by gas-filled spark gaps nnected across the filter inputs. Ordinary carbon resistors re used as the series elements in the circuits to be metered it was thought that they would be more reliable than high bility carbon or wire-wound types under surge conditions, l that this advantage would outweigh the resulting loss in bility of calibration.

The quantities which were measured included the ion rce oscillator and extractor current and voltage, focus tage, the voltage applied to a palladium osmosis tube, the ssure of hydrogen in the ion source, and the belt, tube, istor and gas currents. In one set of experiments a metal plumb bob suspended on a conducting chain was used to short out parts of the stack above the intershield. It was raised or lowered using the control system and its position was indicated on one of the metering channels. The equipment has worked reliably for more than a year. The accuracy on the high current channels is about 2%, but on the low current channels, in which cathode follower amplifiers had to be used, it is limited to about 5% by the carbon resistors used in the input circuit.

Research Laboratory,
Associated Electrical Industries Ltd.,
Aldermaston,
Berkshire.

B. Millar
K. Firth
D. R. Chick

A note on the hole, slot and plane method

In his note on the hole, slot and plane method for locating a rigid body, Mr. Darby* emphasizes the necessity of using a tapering hole with three plane faces rather than a simple conical hollow and suggests a technique for milling the surface to achieve this in cases where a simple punching tool cannot be employed.

It is interesting to note that the trihedral hollow recommended for purposes of kinematic location can be satisfactorily produced in brittle materials, such as glass and ceramics, by the high-frequency reciprocating device earlier described.†

Mullard Research Laboratories,
Salfords,
Surrey.

E. A. Neppiras

* Darby, J. F. *J. Sci. Instrum.*, **31**, p. 224 (1954).

† Neppiras, E. A. *J. Sci. Instrum.*, **30**, p. 72 (1953).

Straightening curvilinear records

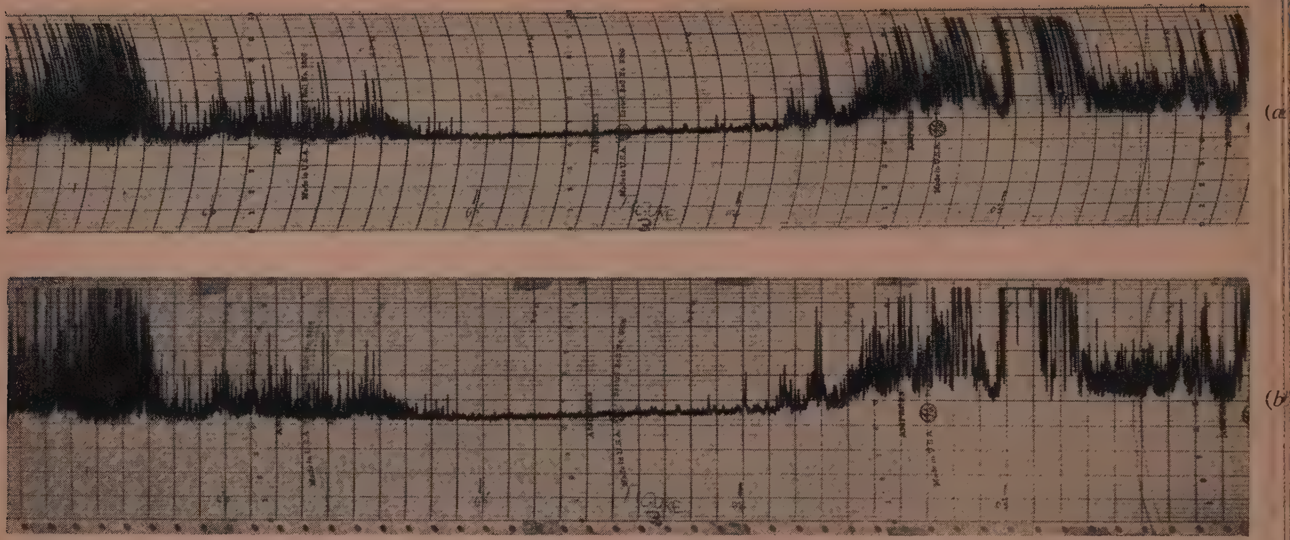
In a number of commonly-used recording meters, the tip of the pen moves in a circular arc, and there is considerable distortion of the record compared with a simple Cartesian representation of amplitude against time. Unless care is taken, this can lead to a false interpretation of the record. For example, if two records are made of the same quantity with identical instruments, but with the zero shifted to a different position on the scale in each case, the two records appear to have quite different shapes and they cannot be superimposed for direct comparison. It is also difficult to compare the records from different types of recording instruments.

The figure shows the result of applying a simple photographic technique for the removal of this distortion. Part (*a*) is a direct photograph of the original record and part (*b*) the copy of the record in rectangular co-ordinates.

The correction for curvature is obtained by balancing the curvature of the record graticule by an opposite curvature introduced by wrapping the record around a curved surface. The required surface is a cone, with vertex directly underneath the camera lens, and placed with one generator horizontal. The centre line of the record is laid along this generator with the convexity of the graticule towards the camera. The height of the camera lens must be $R\cot\theta$ where R is the radius of the graticule circles and θ is the semivertical angle of the cone. The wedge distortion introduced by the oblique photography is removed by one of the techniques described by Bracewell.‡ For part (*b*) of the figure, the distortion was removed by tilting the enlarger when making the print.

---

‡ Bracewell, R. N. *J. Sci. Instrum.*, **32**, p. 37 (1955).



(*a*) Original record. (*b*) Record reproduced with rectangular co-ordinates.

The correction is exact only along the centre line of the record, but is correct to a first order of approximation off the centre line, and to the second order when the angle of incidence is about 45°. The figure shows that, in the present case ($\theta = 6°$, $R = 5{\cdot}8$ in., height of lens = 55 in.), the correction is very satisfactory even at the edges of the record, the only visible discrepancies being due to crinkling of th record.

Division of Radiophysics,
Commonwealth Scientific and
Industrial Research Organization,
Sydney, Australia.
C. A. Shain

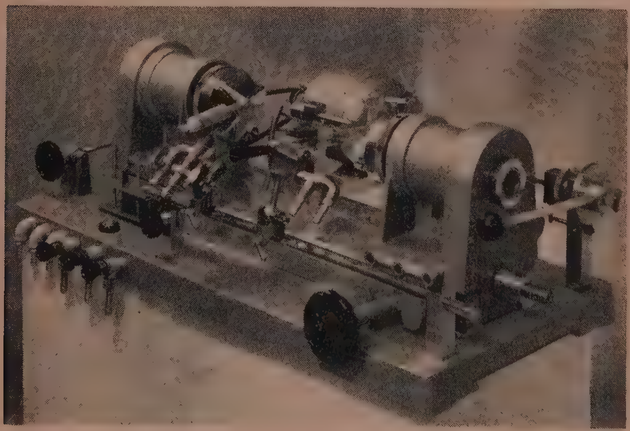
New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improve products. The Institute of Physics assumes no responsibility for the statements given below: information for these has bee taken from literature supplied.

Glass working machine. W. Edwards and Co. (London) Ltd., Manor Royal, Crawley, Sussex.

The Edwards glass working machine, model G.3, has been developed to provide glass working facilities for a wide range of tasks, such as glass blowing, forming and sealing operations. It can be used both for individual items and repetition work.

The machine is mounted on a cast base with a fixed headstock and a traversable tailstock operated by a conveniently placed hand wheel. The rotating spindles are synchronously driven, compensated for backlash, with all shafts running on easily replaceable bearings; the rotating parts are protected from heat radiation by a sliding metal cover. The drive i taken from an integrally mounted ¼ h.p. electric motor an the spindle speed is infinitely variable between 120 an 500 rev/min. An adjustable burner bar runs along the fron of the machine, a gas supply point for two burners being o the left of the base. Two burners are supplied, a cannon typ with five interchangeable jets and mounted on a ball-jointe clamp and a crossfire multi-jet burner. An adjustable too mounting bar is arranged at the rear fitted with an adjustabl stop which can be locked to pre-set limits. The standar forming tool supplied incorporates a rectangular carbon ti which can be shaped as required. Spare carbon tips ar supplied. Alternatively the tailstock can be disconnecte from the drive and its spindle locked to hold tools for glassware held in the headstock chuck. The tailstock traverse then acts as a tool adjuster. The flanging tool supplied ha a cylindrical carbon tip which can also be shaped as required Gas, compressed air and oxygen can be piped to connexion on the left-hand side of the base, provision for feeding controlling and connexion to the burners being incorporate in the standard unit.



Glass working machine

Corrosion voltmeter. Cambridge Instrument Co. Ltd 13 Grosvenor Place, London, S.W.1.

Corrosion is basically an electro-chemical action and b measuring the electric potential between the structure and it environment it is possible to obtain an accurate estimate c the location and extent of corrosive action taking place This is particularly useful in the case of buried or immerse structures. The Cambridge corrosion voltmeter has bee eveloped in conjunction with Cathodic Corrosion Control td. The instrument incorporates a Unipivot voltmeter aving ranges of 1·2 and 5 V, together with a potentiometer onnected in series with the corrosion voltage to be measured nd adjusted until the voltmeter reading is zero. This otentiometer "backing off" voltage is then measured on the oltmeter and represents the equivalent of the e.m.f. developed etween the structure and the soil. The manufacturers claim hat with care, measurements may be made in circuits with p to 1 MΩ resistance.

The instrument is self-contained and has been designed for eld use. The resistance when used as a directly connected oltmeter is 50 kΩ in the 1·2 V range and 208 kΩ in the V range. Full-scale current is 24 μA. The current for the otentiometer is supplied from a self-contained dry battery nd is of the order of 10 mA. The instrument can also be sed, in circuits of relatively low resistance, as a two-range igh resistance voltmeter.

utomatic point counter. James Swift and Son, Ltd., 113–115*a* Camberwell Road, London, S.E.5.

he Swift automatic point counter is an instrument for the nalysis of any material or mixture, the constituents of which re identifiable under a microscope. The eyepiece of the nicroscope is fitted with a fine cross-lined graticule, the entre of which is used as a point of location. The instrument nay be fitted to a microscope with a transmitting or an ncident illuminator and it can therefore be used for the nalysis of opaque materials such as thick mineralogical pecimens, alloys, etc. The apparatus can be used with bjectives of any power.

The instrument consists of a servo-operated traversing arriage which is attachable to the stage of any conventional nicroscope and is coupled to an electrical recording or ounting unit under the control of the observer. The traverse f the specimen carriage is not continuous, but is broken nto a series of equally-spaced steps. These are triggered lectrically in the "horizontal" direction by switches in the ounting unit, and spaced by a hand-operated knob in the "vertical" direction. A series of push-buttons are mounted n the counting unit and the operator depresses the appropriate utton when the particle coinciding with the cross-wires has een identified.

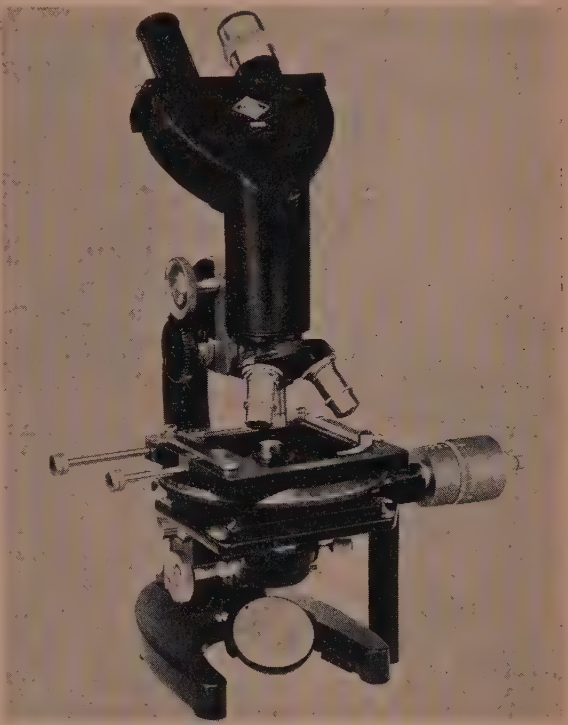
The stage unit measures 5 × 4½ × 1¼ in. (approximately) verall. The smallness of the unit permits the full rotation f the stage of most modern research polarizing microscopes. ince the whole mechanical unit, with the specimen mounted n it, is a complete unit, the position of the stage of the nicroscope is of no importance.

The instrument can be supplied with one of four "hori-ontal" intervals of traverse of $\frac{1}{20}$, $\frac{1}{10}$, $\frac{1}{6}$ and $\frac{1}{3}$ mm approx. he unit is designed so that the interval may be altered at ny time by the simple change of two gear wheels within he unit. The "vertical" spacing knob (on all instruments) s made to move the carriage a distance of 0·3 mm between ach "click" position. The counting unit is supplied, for the tandard model, with seven electrical four-digit counters, of he standard Post Office pattern. Six counters are for the abulation of six possible constituents in the specimen, and re operated by the depression of their appropriate push-uttons. The seventh counter and the mechanical stage unit re operated from contacts which are fitted to all the counters nd therefore give the total of all the individual recordings. y means of a press-switch the seventh push-button may be nade to actuate the carriage only, over holes or useless ortions of the specimen, without recording. If there are seven constituents in the material to be analysed, or if it is desired to count the "blank" areas, the seventh button can be used to operate the seventh counter. When connected thus, the seventh counter will still record the total of all counts, the seventh count being obtained by subtraction.

Binocular microscope for examination of nuclear plates. W. R. Prior and Co. Ltd., Northgate End, Bishop's Stortford, Herts.

This microscope is equipped with a high-power binocular body with inclined eyepiece tubes. Attached to the right-hand focusing head of the fine adjustment is a large drum 1·25 in. in diameter calibrated in approximately 3 μ divisions which is used for the measurement of emulsion thickness, angle of dip of tracks, etc.

The stage of the microscope is in three parts consisting of an upper stage, a circular stage and a lower stage. The upper stage has an *X*-movement of about 3·5 in. actuated by a worm drive and a *Y*-movement of 2 in. actuated by rack and pinion. Both movements can be read by vernier to 0·1 mm. An adjustable plate holder accepts plates up to 4 × 4 in. The upper stage is mounted on a circular stage which can be rotated over 300° and clamped in any orientation. It is fitted with a scale and vernier reading to 0·1°. The lower stage has an *X*-movement of 1 in. and is moved by a micrometer having a barrel 1·5 in. in diameter calibrated in 5 μ divisions. A spring device in the barrel enables movements of 50 μ or multiples thereof to be made without interrupting observations.



Microscope for examination of nuclear plates

Once a particular point on the plate is brought to the centre of the field of view by means of the upper stage, the plate may be rotated by the circular stage until the track under observation is approximately parallel to the direction of movement of the lower stage. The lower stage may then be used in conjunction with a micrometer eyepiece or eyepiece scale to determine the scattering of the track. At one setting of the upper stage 2·5 cm of the track may be examined and, by re-setting, tracks up to 10 cm in length may be investigated.

Notes and comments

Booklet on the theory of lenses

The fifth booklet in The Institute of Physics' Monographs for Students Series has just been published and is entitled *Theory of Lenses*; the author is Mr. E. W. H. Selwyn of Kodak Ltd. Although this little book is about theory, its object is practical; the author has attempted to deal with the subject using not much, if any, more mathematics than is acquired at a grammar school. The problems that have been added are such that they cannot be solved by mere substitution in a correctly remembered formula.

This series is intended for general reading by students such as those in the first two years of a degree course in either science or engineering or for those reading for Higher National Certificates. Copies of the booklets may be obtained from any bookseller, price 5*s.* each, or direct from The Institute of Physics, 47 Belgrave Square, London, S.W.1. (Members of the Institute are entitled to copies at the reduced rate announced in the *Bulletin*.)

The Physical Society's annual exhibition of instruments and apparatus

As announced in the December issue of this *Journal*, The Physical Society's 39th annual exhibition of instruments and apparatus will be held in the New Hall of the Royal Horticultural Society, Westminster, London, S.W.1, from 25 to 28 April, 1955 (inclusive). The exhibition will be open from 10 a.m. to 8 p.m. on 26 and 27 April and from 10 a.m. to 5 p.m. on 28 April. Although it will also be open until 8 p.m. on the first day (25 April) the morning (10 a.m. to 2 p.m.) has been reserved for members of the society and sister bodies.

Tickets available for any one day, may be obtained from The Physical Society, 1 Lowther Gardens, Prince Consort Road, London, S.W.7. Members of The Institute of Physics may obtain tickets from the Institute's office.

Journal of Nuclear Energy

The first issue has appeared of the new quarterly to be devoted primarily to the publication of technical articles from the staff of European nuclear energy projects and their associated industrial groups. In his foreword, Sir John Cockroft says that it is hoped that its establishment will "promote that interchange of ideas which is the basis of scientific and technological development in peace." This issue before us is one of 92 pages measuring 6¾ × 10 in. and is well printed and produced. It contains ten contributions, seven of which are from Harwell, covering a wide range of subjects. Papers will be accepted in English, French or German, but English abstracts accompany all the papers. There is a strong International Editorial Advisory Board; the Editors are Dr. J. V. Dunworth (Editor-in-Chief) of Harwell, Dr. J. Guéron of the French Atomic Energy Commission, and Dr. G. Randers of the Joint Establishment fo Nuclear Energy Research, Norway.

The publishers are the Pergamon Press Ltd. of Maxwe House, Marylebone Road, London, N.W.1, and the annua subscription price is £4 10*s.* (U.S.A. $12.60), or for individua subscribers certifying that the journal is for their persona use, £3 10*s.* (U.S.A. $9.80).

Catalogue of electrical standards and measuring equipment

We have received a copy of the 1955 catalogue of H. W Sullivan Ltd., of London, S.E.15, entitled "Standards an measuring equipment for electrical research and tele communication engineering." This is a well produced an copiously illustrated book of some 200 pages, much of written in textbook style. The publishers state that it intro duces many new instruments while improvements are adde to those listed in previous editions in an endeavour to preser a thoroughly up-to-date volume.

Erratum

In the paper *An apparatus for the accurate measurement c magnetic susceptibility*, by R. Cini and L. Sacconi, which wa published in the February 1954 issue (Volume 31) of th *Journal*, on p. 58

for "... $\theta = L \times M \times G^{-1} \times r^{-4}$. In this case, $L = 16$ c
$M = 11$ dyn/cm, $G = 3 \times 10^{11}$ dyn, and $r = 3{\cdot}25$
10^{-3} cm; ..."

read "$\theta = (2/\pi) \times L \times M \times G^{-1} \times r^{-4}$. In this case, L
16 cm, $M = 11$ dyn × cm, $G = 3 \times 10^{11}$ dyn × cm^{-}
and $r \simeq 2{\cdot}9 \times 10^{-3}$ cm;"

British Journal of Applied Physics

Contents of the March issue

ORIGINAL CONTRIBUTIONS

The measurement by ionization methods of the peak kilovoltage across X-r tubes. By J. R. Greening.
Elastic work involved in rolling a sphere on another surface. By D. Tabor.
Role of partition coefficient in permeability of surface layers with low diffusi coefficient. By G. R. Lester.
Studies of the viscosity and sedimentation of suspensions. Part 3—The se mentation of isometric and compact particles. By S. Gurel, S. G. War and R. L. Whitmore.
The resistance of an elliptic plate. By E. E. Jones.
The estimation of the specific surface of a soil from mechanical analysis da By J. R. H. Coutts.
Formulae for the transformation of indices in twinned crystals. By K. Andrews and J. W. Johnson.
Ionic bombardment heating of magnetron cathodes. By A. E. Barrington.
Single exposure photography of a high speed event. By K. R. Tuson.
A method of measuring the intensity distributions of radio-frequency electric a magnetic fields in resonant cavities. By J. G. Linhart and T. H. B. Baker
Some lithium iodide phosphors for slow neutron detection. By K. P. Nichols and G. F. Snelling.

NOTES AND NEWS

Correspondence

Electric breakdown at very low gas pressures. From J. W. Leech.
A method of making silicon junction diodes. From J. W. Granville.

New books

Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principles, construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Square, London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation of contributions*. (Price 2*s.* 6*d.* including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon application from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, London, E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within 60 days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of address or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £4 per volume ($11.50 U.S.A.), including index (post paid) payable in advance. Single parts, so far as available, may be purchased at 8*s.* each ($1.15 U.S.A.), post paid, cash with order. Orders should be sent to The Institute of Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

An electronic phase-shift tube for microwave frequencies

By D. H. Pringle, B.Sc., Ph.D., A.Inst.P., Ferranti Ltd., West Granton Road, Edinburgh

[*Paper received* 2 *November*, 1954]

The transmission of microwave radiation through an electron gas supported by a gas discharge plasma situated in a waveguide structure is discussed for the case in which the electron collision frequency is much less than the microwave frequency, and an expression is derived for the phase shift arising from the change in guide wavelength. A gas discharge phase-shift tube has been developed on this principle and efficient action obtained by using the negative glow region of the discharge. The performance of the tube is discussed in detail.

THEORETICAL CONSIDERATIONS

he theory of Lorentz,(1) describing the motion of charged articles subject to random collisions and oscillating under ie action of an alternating field, can be applied to the case f a discharge plasma supporting an electron gas. A recent aper by the author(2) gives the mathematical analysis in etail, and it will suffice here to give the derived expression or the complex conductivity of the discharge in the field

$$\sigma = \sigma_r + j\sigma_i = \frac{ne^2}{m}\left(\frac{\nu}{\nu^2 + \omega^2} - \frac{j\omega}{\nu^2 + \omega^2}\right) \qquad (1)$$

here σ_r and σ_i are the real and imaginary components of ie complex conductivity σ, n is the electron density, ν is the ollision frequency of electrons and gas molecules (considering nly elastic collisions), ω is the angular field frequency and and m the charge and mass of the electron. Although this ieory ignores the distribution in energy and in free path of ie electrons it may be shown(2) that the value of σ is little ffected by considering these factors.

Now we may write Ampère's law for an isotropic medium ithout space charge and with permeability unity as

$$\nabla \Lambda H = \frac{1}{c}\dot{D} + \frac{1}{c}I \quad \text{(m.k.s. units)}$$

ı the usual notation.

If we write the dielectric constant of free space $\Sigma_0 = D/E$ nd $E = E_0 \exp(j\omega t)$ we have

$$\nabla \Lambda H = (j\omega/c)\Sigma_0 E + (\sigma E/c)$$

If σ is complex then Σ_0, which is a measure of the current ı quadrature with E, must be replaced by a new dielectric onstant

$$\Sigma = \Sigma_0 - (\sigma_i/\omega)$$

hile the dissipative current density is $\sigma_r E$.

Assuming that $\nu \ll \omega$ and using the value of σ_i from quation (1) we obtain

$$\Sigma = \Sigma_0[1 - (ne^2/m\Sigma_0\omega^2)] \qquad (2)$$

Thus the effect of the electron gas supported by the plasma to reduce the dielectric constant of the propagating medium. /hen $ne^2/m\Sigma_0\omega^2 = 1$, $\Sigma = 0$ and this corresponds to plasma esonance. The value of electron density n for plasma esonance is $1 \cdot 1 \times 10^{12}$ electrons/cm^3 for a frequency of 350 Mc/s. It may be noted that the value of electron density ading to cut-off in the transmission, corresponding to the zero value of the phase length of the discharge-filled waveguide, is shown in reference (2) to be given by $5 \cdot 3 \times 10^{11}$ electrons/cm^3 at this frequency, and so cut-off is reached considerably before plasma resonance as the electron density increases.

We may write generally

$$\frac{\lambda'_g}{\lambda} = 1\Big/\sqrt{\left[\frac{\Sigma}{\Sigma_0} - \left(\frac{\lambda}{\lambda_c}\right)^2\right]}$$

where λ'_g is the guide wavelength in the medium of dielectric constant Σ, λ is the free-space wavelength and λ_c is the cut-off wavelength.

The shift in phase δ, expressed in (rad/2π), due to the presence of the discharge plasma supporting the electron gas, can be written

$$\delta = L[(1/\lambda_g) - (1/\lambda'_g)]$$

where L is the length of the plasma.

It is simple to show that if $(\delta\lambda/L)^2$ is small we may write

$$\Sigma/\Sigma_0 \simeq 1 - 2\delta\lambda/L\sqrt{[1 - (\lambda/\lambda_c)^2]} \qquad (3)$$

On substituting the value of Σ/Σ_0 from equation (2) we obtain to a first approximation

$$n \times 10^{-4}/f^2 = 2\delta(\lambda/L)\sqrt{[1 - (\lambda/\lambda_c)^2]}$$

where f is the signal frequency in Mc/s and n is expressed in electrons/cm^3.

Now $\qquad \lambda/\lambda_g = \sqrt{[1 - (\lambda/\lambda_c)^2]}$

Thus $\qquad n \times 10^{-4}/f^2 = 2\delta\lambda^2/L\lambda_g$

or $\qquad n \times 10^{-8}L/2c^2 = \delta/\lambda_g \qquad (4)$

It is therefore seen that if the two assumptions made are valid, namely (1) $\nu_c \ll \omega$, and (2) $(\delta\lambda/L)^2$ small compared to $2\delta\lambda/L\sqrt{[1 - (\lambda/\lambda_c)^2]}$, that the ratio of phase shift to guide wavelength is constant for given values of electron density and plasma length. This property of such a device is referred to later.

From equation (4) it may be seen that for $L = 8 \cdot 4$ cm and $\lambda_g = 4 \cdot 6$ cm, the approximate values employed below, $n = 2 \cdot 4 \times 10^{11}$ electrons/cm^3 for a phase shift of 180°. Actually the approximation made in equation (4) with regard to the value of $(\delta\lambda/L)^2$ obscures the fact that the phase shift rises to a maximum level when the phase length is zero, this corresponding to $5 \cdot 3 \times 10^{11}$ electrons/cm^3 for $\lambda_g = 4 \cdot 6$ cm.

DESIGN DETAILS

A considerable amount of work has been performed in the Federal Telecommunications Laboratories of recent years [see, for example, reference (3)] towards the production of a suitable gas discharge modulator tube. Two possible methods of approach to the problem investigated were:

(a) an attenuating plasma in a resonant structure with the real part of the complex conductivity $\sigma_r \gg \sigma_i$;

(b) a phase-shifting plasma with $\sigma_i \gg \sigma_r$, designed so that the effective distance between elements in a resonant structure was altered with change in the electron density of the plasma in a structure between the elements.

The type of structure finally adopted by the Federal Telecommunications Laboratories employed an attenuating plasma in a resonant cavity. They did not find it possible to produce a satisfactory phase-shift tube owing to the fact that a large phase shift was invariably accompanied by large attenuation. With one exception the phase-shift tubes employed the positive column of a glow discharge in a rare gas, which undoubtedly accounted for the poor performance. The positive column is a region of low electron density and high temperature—in other words the very conditions which should be avoided for efficient phase-shift action—in relation to the negative glow region of the discharge. In the latter region it is known from probe measurements that it is not difficult to obtain the order of electron density required ($2 - 3 \times 10^{11}$ electrons/cm^3).

It was decided to investigate the phase-shifting properties of a structure which was developed in this laboratory some years ago as a hot-cathode attenuator tube. As described previously,(4) this tube consists of an axial filament mounted in a section of rectangular waveguide by means of support arms in the side walls, the tube being closed by conventional TR-type glass windows. The filament acts as cathode and the waveguide body as anode of a d.c. discharge, so that at the pressures employed (2 mm krypton) a fairly diffuse negative glow sheath surrounds the cathode when the filament heating current is small. As the latter increases, however, the negative glow collapses on to the cathode and at the transition between a glow and an arc discharge the microwave attenuation reaches a sharp peak and then rapidly falls to zero when this critical heating current is exceede It was found that the phase shift introduced by this tube al exhibited a sharp maximum at this value of filament curren but what was even more interesting, a considerable pha shift could be obtained with a *cold* cathode discharge with little or no attenuation.

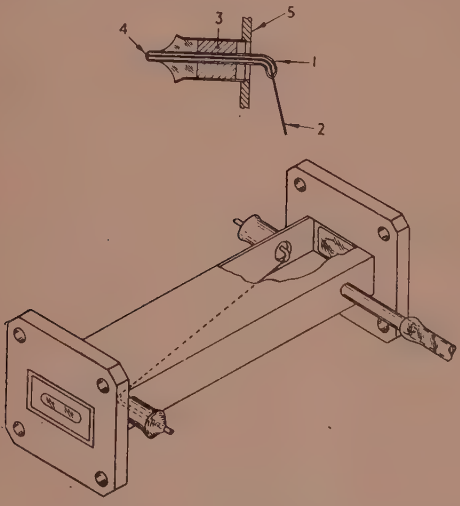


Fig. 1. Details of phase shift tube

(1) glass sheathed Kovar tube; (2) cathode wire; (3) pyrophillite locating bush; (4) brazed seal; (5) waveguide wall.

Some work was then carried out to determine the mo suitable cathode configuration in order to obtain a broa band match with the discharge running. As a compromis between matching and space limitation it was found that satisfactory performance could be obtained if the cathode wa inserted at an angle of about 12° between glass-sheathe Kovar tubes mounted in the side walls of the waveguide ar penetrating ⅛ in. into the guide. A sketch of the tube shown in Fig. 1. The cathode, of 0·015 in. diameter thoriate tungsten wire, passes through the Kovar tubes and a braze seal is made at the far ends of the tubes. The distance betwee the glass windows and the support tubes is arranged to b $\lambda_g/4$ at 9250 Mc/s, so that the overall length of the tube 4·28 in. An external getter assembly is provided and this fired after evacuation and baking of the tube.

PERFORMANCE

Typical operating characteristics. The characteristics the tube were measured in a balanced waveguide syste consisting of two 3 dB couplers with the tube in one ar and a calibrated dielectric phase shifter and moving-va attenuator in the other arm.

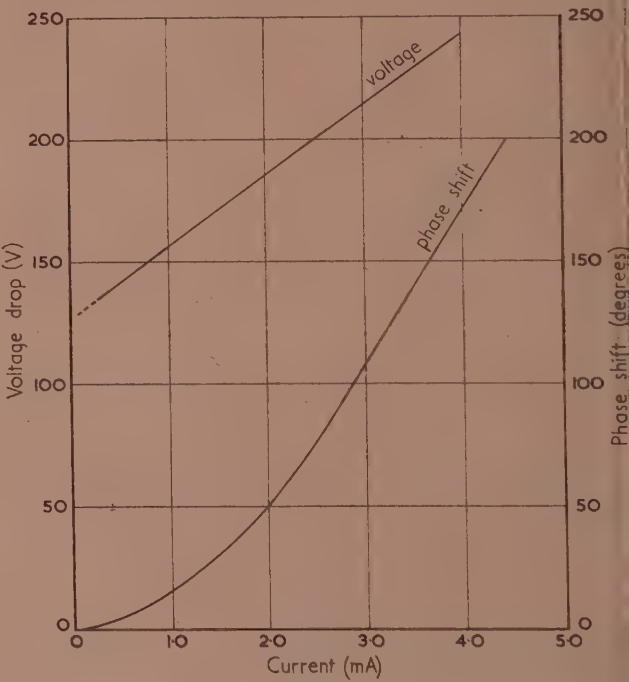


Fig. 2. Typical characteristics of phase shift tube

(2 mm of mercury of krypton; $f = 9250$ Mc/s).

The following figures refer to the characteristics of a tu which has been aged for 50 h with a discharge current 2 mA. It was found that the change in the phase shift-curre and voltage-current characteristics with time after this peri was negligible and, indeed, a tube has been run for 500 with little or no change in voltage standing-wave rati ertion loss, phase shift, attenuation and running voltage. pical curves of phase shift and voltage against current are roduced in Fig. 2; in this case the tube is filled with ypton at a pressure of 2 mm of mercury. It may be noted, wever, that the optimum krypton gas fill appears to be ghtly lower than this, nearer 1 mm of mercury. The enuation or interaction loss corresponding to a phase shift 180° (about 4 mA) is about 0·3 dB, while the cold or sertion loss of the tube is as shown in Table 1.

Table 1. *Insertion loss of phase shift tube*

Frequency (Mc/s)	*Insertion loss (dB)* *After 50 h*	 *After 500 h*
8950	0·45	0·80
9250	0·10	0·20
9550	0·25	0·50

It is seen that after 500 h running at 2 mA that the total ss (interaction + insertion) is 0·50 dB at the centre fre-ency, 9250 Mc/s. The voltage standing wave ratio values zero current and at 3 mA current are given in Table 2 the centre frequency and two frequencies 300 Mc/s apart.

Table 2. *Voltage standing wave ratio of phase shift tube*

Hours	*Voltage standing wave ratio*					
	8950 Mc/s		*9250 Mc/s*		*9550 Mc/s*	
run	*Zero current*	*3 mA*	*Zero current*	*3 mA*	*Zero current*	*3 mA*
50	1·098	1·227	1·048	1·111	1·361	1·066
500	1·148	1·373	1·037	1·048	1·410	1·026

Ratio of phase shift to guide wavelength. Measurements ere taken to see if equation (4) was valid with regard to the nstant ratio of (δ/λ_g) (see Table 3). The discharge current as maintained at 3·25 mA.

able 3. *Ratio of phase shift to guide wavelength as function of frequency*

Frequency (Mc/s)	*Phase shift degrees*	*Guide wavelength* (λ_g)	$\frac{\text{Phase shift}}{\lambda_g}$
8950	131	4·923 cm	26·7
9050	125	4·804	26·0
9150	126·5	4·696	26·9
9250	125	4·595	27·2
9350	120	4·497	26·7
9450	124	4·404	28·0
9550	118	4·319	27·3
9650	113	4·236	26·7
9750	105	4·155	25·5

The relatively small variation in the ratio of (δ/λ_g) indicates at the assumptions made in the derivation of equation (4) e valid at least to a first approximation. Unfortunately it ould be of more practical importance in a balanced wave-uide system if the product of phase shift and guide wave-ngth were constant, as then the dispersion introduced by e discharge-filled waveguide would equal that of the empty aveguide.

Response time. The build-up and recovery times of the be discharge to a modulating waveform were measured by applying first a sine wave and then a square wave modulation to the cathode. With a gas fill of 2 mm krypton the output signal amplitude from the detecting crystal was 3 dB down at only about 2 kc/s, maintaining the input modulation amplitude constant. A range of gases at different pressures was employed to find the optimum performance and the recovery and build-up times to square wave modulation at 600 c/s noted. With all the rare gases the recovery time improved considerably as the pressure was increased beyond about 5 mm of mercury, indicating that recombination is a much more effective mechanism with this tube geometry than diffusion. With argon at a pressure of 10 mm of mercury, for example, the recovery time was only 30 μs (to 3 dB down) but the phase shift for 6 mA current was only 60° and the attenuation 8·0 dB; the large attenuation is, of course, due to the large ratio of collision frequency to field frequency at this pressure. It was attempted to use small admixtures of hydrogen and nitrogen in conjunction with rare gases in order to reduce recovery times, but this proved unsuccessful as even partial pressures of hydrogen and nitrogen as low as 0·5 mm of mercury made it impossible to obtain more than a few degrees phase shift. It was believed that helium, the lightest rare gas, might on account of its high diffusion rate have a more rapid response, but the degrees/dB ratio was much lower than with the other rare gases. If modulation frequency response is held to be important then the most suitable compromise between the degrees/dB ratio and the response time is obtainable with either krypton or argon at a pressure of 6 mm of mercury when one can obtain 180° phase shift with just over 1 dB attenuation, the response time being 50 μs.

A considerable improvement in response time can be brought about by electronic means, involving shaping the applied modulation pulses. If one applies a pulse to the cathode with a large negative spike at the leading edge the build-up time can be reduced to a few microseconds, while a positive overshoot on the trailing edge can reduce the recovery time to about 20 μs with krypton at a pressure of 2 mm of mercury. The latter action is due to the sudden sweeping of the electrons out of the vicinity of the filament by the reversal in polarity.

It is interesting to note that with a sine-wave modulation applied to the discharge current and the mean level of tube current adjusted so that the measuring system is nearly balanced, the output waveform is twice the frequency of the modulating frequency as the system passes through balance twice in each cycle.

ACKNOWLEDGEMENTS

The author wishes to thank Ferranti Ltd., who have provided the facilities for carrying out this work, and the Admiralty for their sponsorship and permission to publish this paper.

REFERENCES

(1) Lorentz, H. A. *The Theory of Electrons*, p. 309 (New York: Dover Publications, 1916).

(2) Bradley, E. M., and Pringle, D. H. *J. Brit. Instn Radio Engrs*, **15**, p. 11 (1955).

(3) *Federal Telecommunications Report* (6–*A*) *on Modulator Tubes* (1952).

(4) Pringle, D. H., and Whitmore, E. J. *Ferranti Report on Microwave Electronic Attenuators* (June 1951).

A generator for very small direct currents

By K. D. E. Crawford, A.M.I.E.E.,* Mullard Radio Valve Co., Ltd., Mitcham, Surrey

[*Paper first received* 21 *September, and in final form* 3 *December*, 1954]

Currents from 2×10^{-17} to 2×10^{-10} A are generated by applying a linear voltage change, developed by an electronic circuit, to a special output condenser. A source with a resistance greater than $10^{16}\ \Omega$ is thus obtained which makes it particularly suitable for the calibration of current measuring devices and for the measurement of high value resistances.

The generator described below depends in principle on the method, first described by Wikstrom in 1933,⁽¹⁾ of producing very small direct currents by applying to a condenser a voltage with a linear rate of change. With this system a current source of virtually infinite resistance is obtained which makes it ideal for use in the measurement of very high value resistances, as has been described by Wikstrom and others.⁽¹⁻³⁾

The generators so far described have used a mechanically driven slide wire in order to get the linear sweep voltage. In the present instrument this is obtained by means of an electronic circuit and is adjustable over a wide range, so that the output current can be varied between limits of approximately 2×10^{-17} and 2×10^{-10} A.

The basic principle of operation is best described by reference to Fig. 1. In this C_1 represents the output capacitor of the generator to which the linear voltage change $V = \alpha t$ is applied whilst R_1 and C_2 represent the resistance and capacitance of the load connected to the generator.

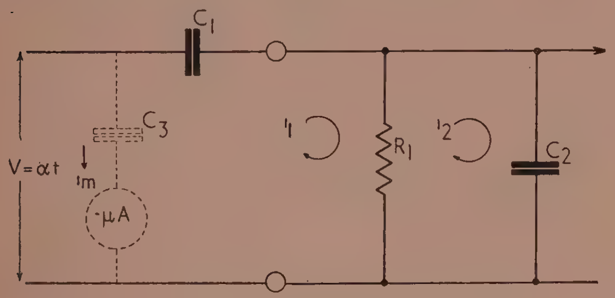


Fig. 1. Principle of operation

Then starting from $V = 0$ at $t = 0$ we have:

$$i_1 = \alpha C_1 \left\{ 1 - \exp\left[-\frac{1}{R_1(C_1 + C_2)} t \right] \right\}$$

and

$$i_2 = C_2[\alpha - (i_1/C_1)]$$

Therefore i_1 exponentially approaches a constant value at a rate depending on the time constant $R(C_1 + C_2)$ and the limiting condition is:

$$i_1 = \alpha C_1 = (dV/dt)C_1$$
$$i_2 = 0$$

The condenser C_2 is then charged to a constant voltage and the whole of the input current i_1 is passing through the resistance R_1. This current is determined solely by the rate of change of the input voltage and the capacitance of the condenser C_1 and is quite independent of the load resistance and capacitance.

MONITORING SYSTEM

The linearity and rate of change of the input voltage can be measured by connecting a large condenser of known value and possessing a high insulation resistance, in series with a d.c. microammeter across the supply as shown dotted in Fig. 1. The current through the meter will then be:

$$i_m = (dV/dt)C_3$$

and the output current i_1 can be determined in terms of a measured current and the ratio of the two capacities. Thus

$$i_1 = i_m(C_1/C_3)$$

This method is not used in the present instrument because it involves the use of a very sensitive microammeter and special precautions have to be taken to prevent damage to this meter when the voltage is returned rapidly to its starting point. Instead, the microammeter is replaced by a known resistance and i_m is determined by measuring the voltage drop across the latter by means of a valve voltmeter. In the generator this resistance and the condenser C_3 form a differentiating circuit which controls the rate of change of the input voltage.

DESCRIPTION OF APPARATUS

A complete circuit diagram of the generator is given in Fig. 2. The rate of change of the output voltage is controlled by a differentiating circuit formed by C_2 and R_8, R_9 or R_{10}. The voltage developed across the resistive part of this circuit is applied to the grid of the control valve V_2 which in turn controls the series valve V_1 and therefore the output voltage. A reference voltage is supplied by the neon stabilizer tube V_4 in the cathode circuit of V_2. The resistors, which form part of the differentiating circuit, are returned to the slider of the potentiometer R_{12}, which is connected across the reference voltage, and therefore the rate of change of the voltage between the negative line and the cathode of V_1 is determined by the constants of the differentiating circuit and by the setting of R_{12}.

The cycle of operation starts with the cathode of V_1 at about 140 V positive and ends when this point has risen to some 320 V; the end point being indicated by the extinguishing of the neon tube V_3. The voltage is then reset manually by means of the switch SW_2 which, in the "reset" position, connects the grid of the control valve to the junction of the resistors R_{13}, R_{14} and discharges C_2.

The choice of a suitable rate of change is determined mainly by the requirement of having a reasonably long operating time for one cycle of operation and by the choice of a convenient size for the air spaced output condenser C_5.

With R_{12} adjusted to give half scale deflexion on the monitor meter M the sweep circuit operates at a rate of 0·1 V/s on the first six positions of the range switch SW_1; on the two highest ranges this is increased to 1·0 V/s and 10 V/s by switching lower value resistances (R_9, R_{10}) into e differentiating circuit. Lower rates of change are applied the output condenser on the first five positions of SW_1 inserting a decade attenuator between it and the sweep rcuit.

---

* Now at E.M.I. Engineering Development Ltd., Wells, Somerset.

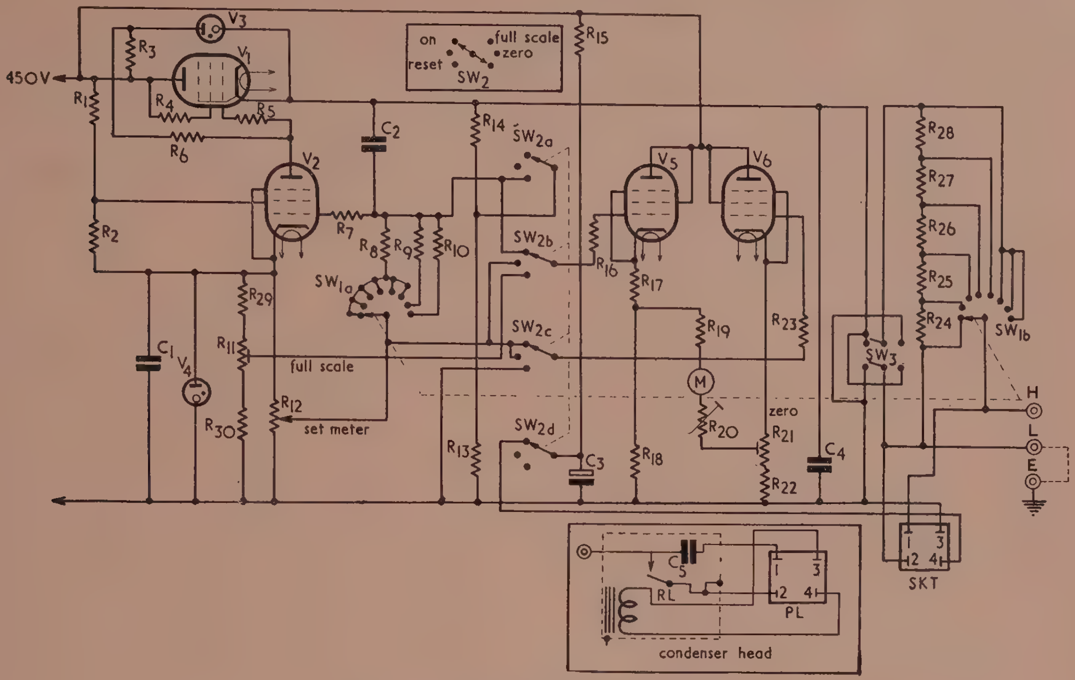


Fig. 2. Circuit diagram of generator

R_1 = 39 kΩ
R_2 = 22 kΩ
R_3 = 100 kΩ
R_4 = 100 Ω
R_5 = 1 kΩ
R_6 = 220 kΩ
R_7 = 100 kΩ
R_8 = 40 MΩ ⎫
R_9 = 4 MΩ ⎬ ±10%. See note.
R_{10} = 0·4 MΩ ⎭
R_{11} = 100 kΩ

R_{12} = 100 kΩ
R_{13} = 27 kΩ
R_{14} = 18 kΩ
R_{15} = 27 kΩ
R_{16} = 100 kΩ
R_{17} = 3·9 kΩ
R_{18} = 47 kΩ
R_{19} = 120 kΩ
R_{20} = 100 kΩ
R_{21} = 10 kΩ
R_{22} = 39 kΩ

R_{23} = 100 kΩ
R_{24} = 100 Ω
R_{25} = 900 Ω
R_{26} = 9 kΩ
R_{27} = 90 kΩ
R_{28} = 900 kΩ
R_{29} = 10 kΩ
R_{30} = 150 kΩ

C_1 = 0·1 μF
C_2 = 8 μF, ±5%

C_3 = 4 μF
C_4 = 0·5 μF
C_5 = 10 μμF, ±1%

V_1 = EL41
V_2 = EF37A
V_3 = 85A2
V_4 = 85A2
V_5 = EF37A
V_6 = EF37A

$SW_{1a,b}$ = 2 pole, 8 position
$SW_{2a,b,c,d}$ = 4 pole, 3 position
SW_3 = 2 pole, change-over

SKT = 4 pin

M = 300μA

RL = see text
PL = 4 pin

R_8, R_9 and R_{10} are high stability resistors selected in the ratio 100 : 10 : 1 to ±1%.
C_2 is of high insulation resistance polystyrene film dielectric. C_5 is the special output condenser. See Fig. 3.

The output current ranges given by SW_1 when using a μμF output condenser and with the meter reading set to lf scale (×1) are as follows:

Switch position	*Output current (A)*	*Operating time*
1	0	—
2	10^{-16}	30 min
3	10^{-15}	30 min
4	10^{-14}	30 min
5	10^{-13}	30 min
6	10^{-12}	30 min
7	10^{-11}	3 min
8	10^{-10}	18 s

Each of these ranges can be multiplied by a factor of tween 0 and ×2 by adjustment of the "set meter" control 12, the multiplying factor being read on the meter which is aled 0–2.

The operating times given above are sufficient to permit eration into a load having a time constant compatible th the range in use since, in general, the time constant of e load circuit is less when large currents are required.

The monitoring circuit consists of a valve voltmeter which easures the voltage developed across the resistor in the differentiating circuit. The grid of the balancing valve V_6 is returned to the slider of the "set meter" control R_{12} so that the voltage indicated by the valve voltmeter does not include the voltage between this point and the negative line. Thus the two valves V_5 and V_6 should be reasonably well matched but, since full-scale deflexion on the meter corresponds to an input of about 64 V, this matching is not critical.

The reset switch SW_2 has an intermediate position between the "on" and "reset" positions which allows the relay in the output condenser head to spring back and short-circuit the output terminal before the voltage is reset, thus preventing a heavy surge being applied to the load circuit. This switch position is also used for checking the zero of the valve voltmeter and when adjusting the preset zero control R_{21}. In the "reset" position of SW_2 a voltage derived from the neon tube V_4 is used to provide a full-scale check on the meter reading.

The three high stability resistors R_8, R_9 and R_{10} in the differentiating circuit do not need to be of a tolerance closer than ±10% but are selected so that their relative values are in the ratio 100 : 10 : 1 with an accuracy better than 1%. This enables the meter calibration to be maintained on all ranges.

When the "set meter" control is set near to either end of its travel it is possible to switch from one resistor to the other with exactly a ten times alteration in the rate of change of voltage and with no change in the meter reading. With potentiometer R_{12} near to its central position, however, the current through the differentiating circuit on the higher current ranges is sufficient to cause a small change in the reference voltage at the slider of R_{12} and consequently a variation in the meter reading when the range switch is operated on the three top positions. Since the meter calibration is still correct this effect is not important.

The three potentiometers R_{11}, R_{20} and R_{21} are preset controls which only require adjustment when initially setting the calibration of the instrument and are not brought out to the front panel.

The sweep voltage is taken *via* the four-pin socket *SKT* and a flexible screened cable to the output condenser head and is also available when required at terminals *H* and *L*. The lower terminal is normally connected to earth *via* terminal *E* but can be disconnected if it is desired to operate the generator into a load circuit which is not at earth potential, in which case the outer screen of the output condenser must also be isolated from earth. A reversing switch SW_3 enables either a positive or negative going sweep voltage and output current to be obtained.

The condenser C_2 in the differentiating circuit must be a very high quality component if a linear sweep voltage is to be obtained. The defects which are most likely to give trouble are leakage and dielectric absorption currents, which also give rise to errors in the monitoring meter circuit so that any non-linearity may not be shown by the latter. Their presence can be detected by comparing the rates of change near the beginning and the end of the operating cycle, during which there is a considerable change in the voltage applied to the condenser. Another possible defect, which has not been encountered in practice, is a change of capacity with applied voltage.

The total current due to leakage and absorption plus any grid current from the valves must be small compared with the control current through the differentiating circuit which, at a rate of change of 0·1 V/s, is about 0·8 μA. To fulfil these requirements it has been found necessary to use a condenser with a polystyrene film dielectric. With this type of condenser the departure from linearity over the useful range does not exceed 1%.

THE OUTPUT CONDENSER

Since the overall accuracy of the instrument depends only upon the measurement of the rate of change of voltage and upon the output condenser, it is apparent that great care must be taken in the design and construction of this component if errors due to stray capacitance and leakage are to be eliminated. In its physical form the condenser must be considered as a three-terminal network, with capacitance and resistance paths to earth from the input and output terminals.

By far the most important point in the design of this condenser is the elimination of the possibility of any direct leakage path between the input and output terminals. A little consideration will show that with 300 V applied to the input terminal and a fraction of a volt on the output terminal, the insulation must be better than $10^{20}\,\Omega$ if the leakage current is to be negligible compared with the required output current on the lowest range. This high insulation is obtained by making the condenser air-spaced with entirely separate insulators supporting the two electrodes. These insulators are independently mounted on the external screen of the condenser which is connected to the low potential side of the generator, thus avoiding any coupling between input and output due to leakage across the insulators.

The insulating material used to support the output electrode must, of course, be of high quality, since it will appear parallel with the load circuit. For the input terminal no ve special precautions are necessary, however. The capacitan from output to screen of the condenser will appear in parall with the load and is therefore identical with C_2 in Fig. and has the effect of increasing the time constant of t output circuit. It is therefore desirable to make it reasonab small. The input capacity has no effect except when t attenuator is in use, when it adds a small time constant the circuit, as shown in the Appendix.

A summary of the main points in the design of the outp condenser is given below.

(*a*) Input and output leads must be well screened from eac other.

(*b*) All leakage currents across the insulation supporting th two plates must be separately returned to the screen.

(*c*) The insulation of the output terminal must be of ver high quality low leakage material. This insulatio should be protected as far as possible from dust an dirt.

(*d*) Output capacity to be as low as possible.

(*e*) It is desirable to incorporate a shorting relay to prote the load circuit from heavy surges when resetting.

In the present instrument only a moderate order of accura was required and accordingly no attempt was made t construct an accurate physical standard.(3) The presen condenser is made semi-adjustable and is set to within ±1 of the required capacitance by measurement on a capacit bridge.

The design of the condenser is shown in Fig. 3. The oute brass case completely screens the two coaxial cylinders whic form the plates of the condenser. The outer cylinder (1) which is the input electrode, is supported in the case b the insulation (2). The output electrode (3) lies inside thi with an air gap of 2·4 mm and is supported at one en only by a disk of polished polystyrene (4) which is screene from the electrostatic field of the outer electrode by a diaphragm (5). The bolt (6) holding the output electrod continues through the polystyrene disk and forms the outpu

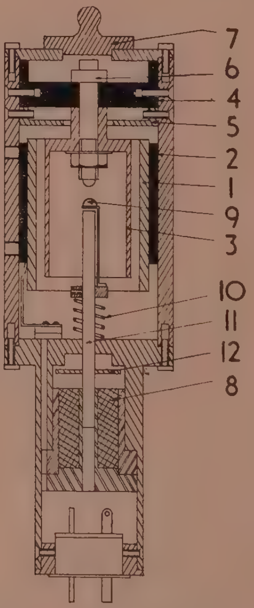


Fig. 3. Output condenser

cket. A dust cover (7) protects the insulation when the ndenser is not in use.

The bottom part of the case contains the relay bobbin (8). he relay contacts (9) are normally kept closed by the return ring (10) on the relay arm (11). When the relay is energized e armature (12) pulls the arm down and opens the contacts.

The condenser is initially adjusted by sliding the outer ectrode in its insulating sleeve and clamping it by means of t screws when the adjustment is correct. The front cover ate and rear portion of the case can both be removed for eaning of the insulation or adjustment of the relay without isturbing the condenser setting. Measurements on the ndenser when assembled gave a resistance of greater than $)^{16}\,\Omega$ and a capacitance of 4 $\mu\mu$F between the output rminal and the screen.

CALIBRATION

The instrument is calibrated by timing the rate of rise of oltage by means of a voltmeter connected across terminals / and L (Fig. 2) with the range switch SW_1 in position 6 0^{-12} A) and with the meter set near to half scale reading. he operating cycle is then restarted without moving the "set eter" control and the meter reading is adjusted by means f the preset control R_{20}, to read ten times the rate of hange actually measured. The switch is then turned to the reset/full scale" position and the meter set to full scale by e preset control R_{11}. The calibration is then correct on all anges.

Alternatively, the rate of change can be measured by means f a large condenser and microammeter as outlined in Fig. 1, rovided that a suitable condenser is available and that the icroammeter is adequately protected when resetting.

APPLICATIONS

The use of similar forms of generator in conjunction with n electrometer for the measurement of very high value esistances has already been described by several writers.$^{(1-3)}$ he method has the advantage that only a small voltage need e applied to the resistance under test and measurements an often be made without removing the resistance from its osition in the circuit.

The present instrument was primarily designed for calirating apparatus used for the measurement of grid current electrometer valves. This apparatus uses high value esistors and an electrometer voltmeter to measure the current; reviously it was necessary to measure the voltage sensitivity nd to make separate measurements of each range resistor order to calibrate the instrument. With the current enerator only a single check of actual current sensitivity on ach range is necessary and the calibration accuracy is of the ame order on all ranges.

The generator can be used for the calibration of any small urrent measuring device and is direct reading, provided that he load into which it is feeding has a direct current path hrough it and a time constant reasonably short compared o the operating time of the generator.

When the load is purely capacitive, as in an integrating ype of current meter, the calibration will only be correct when the load capacitance is much larger than the output ondenser; thus a load of 1000 $\mu\mu$F will give an error of 1%. his error can be allowed for when the load capacitance is nown and can be reduced by providing a smaller output ondenser.

Although designed as a current generator the instrument as other possible applications which are of interest. By omitting the output condenser and using the linear voltage sweep in conjunction with an electrometer of known input resistance it can be used to measure the direct capacitance between two points, such as the coupling capacitance between two sets of fixed plates in a multi-gang variable condenser. This type of measurement is only possible where the insulation resistance is very high or where all leakage currents go to earth with no common coupling path. If these requirements can be satisfied it could, however, be useful for measuring direct capacitance in a complex network containing inductance, such as the interwinding capacities of a transformer.

ACKNOWLEDGEMENTS

My thanks are due to the Mullard Radio Valve Co., Ltd., for permission to publish this article.

REFERENCES

(1) WIKSTROM, A. *Rev. Sci. Instrum.*, **4**, p. 612 (1933).

(2) BAINBRIDGE, K. T., GOLDHABER, M., and WILSON, E. *Phys. Rev.*, **90**, p. 430 (1953).

(3) LYNCH, F. J., and WESENBERG, C. L. *Rev. Sci. Instrum.*, **25**, p. 251 (1954).

APPENDIX

Effect of capacitance to earth on attenuator

Using the notation given in Fig. 4:

at any time t

$$\alpha t = i_1 R_2 + (i_1 - i_2) R_1$$

$$0 = \frac{1}{C} \int_0^t i_2 dt + (i_2 - i_1) R_1$$

Therefore

$$i_1 = (\alpha t + i_2 R_1)/(R_1 + R_2)$$

By differentiating

$$\frac{di_1}{dt} = \alpha \frac{1}{R_1 + R_2} + \frac{di_2}{dt} \frac{R_1}{R_1 + R_2}$$

and
$$\frac{di_1}{dt} R_1 = i_2 \frac{1}{C} + \frac{di_2}{dt} R_1$$

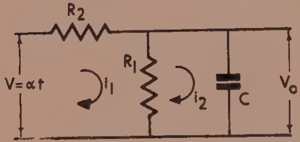


Fig. 4.

Substituting for di_1/dt and solving for i_2 in the last equation gives:

$$i_2 = \alpha C \frac{R_1}{R_1 + R_2} \left[1 - \exp\left(- \frac{R_1 + R_2}{C . R_1 R_2} t \right) \right]$$

After a time determined by the time constant, $(C . R_1 R_2)/(R_1 + R_2)$, i_2 reaches a constant value.

$$i_2 = \alpha C [R_1/(R_1 + R_2)]$$

The voltage across the condenser is therefore rising at a rate i_2/C

$$dV_0/dt = \alpha [R_1/(R_1 + R_2)]$$

The final rate of change of the output voltage is therefore unaffected by the presence of the capacitance C.

A hydrogen Pirani leak detector using a charcoal trap

By T. B. Kent, B.Sc., Grad.Inst.P., United Kingdom Atomic Energy Authority (Industrial Group),
Capenhurst Works, Chester

[*Paper first received* 12 *November, and in final form* 15 *December*, 1954]

A simple robust dynamic leak detector suitable for vacuum proving large numbers of components down to 10^{-3} lμ/s is described. The property of charcoal at low temperatures to absorb a large percentage of atmospheric gases and little hydrogen is used to eliminate irregular pressure pulses caused by impurities in the component and to increase the response of a Pirani gauge when a leak is probed with hydrogen. A charcoal trap is placed between the component and a Pirani gauge on a vacuum unit.

Continual vacuum testing of large numbers of components made imperative the development of a cheap and robust dynamic leak detector which could be operated efficiently by semi-skilled factory workers. One detecting technique examined in this laboratory employed a differential Pirani leak detector$^{(1)}$ and carbon dioxide as a probe gas. Irregular pressure pulses were observed over periods ranging from several minutes to several hours after evacuation, possibly owing to preferential absorption of contaminants on the calcium hydroxide. A palladium ionization gauge was also tried, but after prolonged use the cathode emission fell, probably owing to bombardment of the cathode by excess hydrogen; and although a liquid nitrogen trap was in circuit the impurities in the components being tested caused the palladium window to block. These faults can be eliminated, but only by careful operation of a kind difficult to secure under factory conditions. This paper describes equipment which is not as sensitive but can be used under such conditions by semi-skilled workers, and which is capable of detecting a leak of 10^{-3} lμ/s within five minutes of evacuation. The equipment is cheap, robust and portable, and the extra equipment required is a supply of hydrogen for probing, a charcoal trap, and a coolant for the trap.

PRINCIPLE OF THE METHOD

At low temperatures activated charcoal, previously degassed, readily absorbs atmospheric gases, but will absorb only a small percentage of any hydrogen exposed to it. Hence a charcoal trap, cooled with either liquid nitrogen or solid carbon dioxide and trichlorethylene, placed between a Pirani gauge and a component will ensure that the gauge responds only to hydrogen.$^{(2)}$ To vacuum-prove a component by this technique, it is enclosed in a hydrogen atmosphere which enters the leak and passes the charcoal trap, so inducing a pressure rise on the Pirani gauge. The charcoal trap eliminates the irregular and misleading pressure changes due to components degassing, which are so troublesome when using hydrogen and an untrapped Pirani gauge.

APPARATUS

Fig. 1 is a line diagram of the apparatus used. A small pumping unit [by W. Edwards and Co. (London), Ltd.] consisting of a rotary and two diffusion pumps was employed. The trap itself (Fig. 2) was a 1 in. diameter stainless steel tube 12 in. long filled with 50 g of activated charcoal. It was connected into the normal Edwards circuit through two $\frac{1}{2}$ in. valves (by Saunders Valve Co. Ltd.), inlet and outlet, and by $\frac{1}{2}$ in. nominal bore copper pipe. A standard Pirani gauge (by Metropolitan Vickers Electrical Co. Ltd.) was used; with controls it gave a deflexion of 14 cm on a galvanometer when the air pressure changed by 1 μ. The standard leak referred to in the text is described elsewhere.$^{(3)}$

A blow-off valve was included to ensure that no excessive pressure would be built up in the trap if it were inadvertentl allowed to degas with both the inlet and outlet valves closed. This valve is shown in Fig. 3. In essence it is a plug place

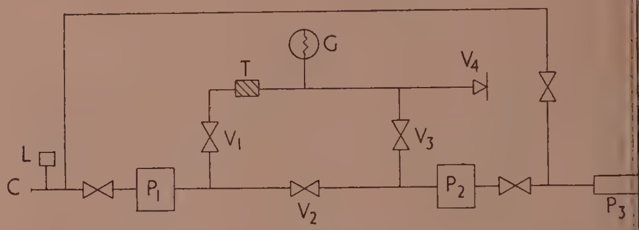


Fig. 1. Vacuum system

L, standard leak; *C*, component connexion; *G*, Pirani gauge; *T*, charcoal trap; V_1, inlet valve; V_2, bypass valve; V_3, outlet valve; V_4, blow-off valve; P_1, primary diffusion pump; P_2, secondary diffusion pump; P_3, rotary pump.

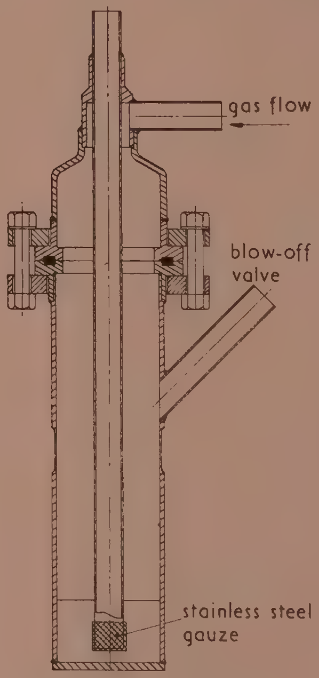


Fig. 2. Charcoal trap

in a Wilson seal which blows out when the pressure in th system is above atmospheric. When the plug has bee blown, the gases escape through the drillings *B*. The plu has a flange *A* which prevents it being expelled.

OPERATION

The component is roughed down and pumped with th diffusion pumps in the normal way for 5 min. With th harcoal trap cooled the outlet valve is throttled, the inlet alve opened and the bypass valve closed. Balloon fabric is sed to shroud the component and hydrogen is blown into his. Bellows and other closed spaces are probed separately.

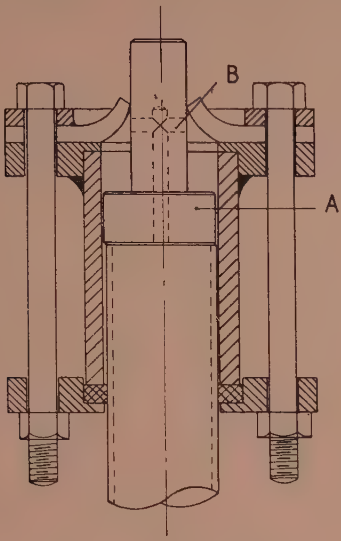


Fig. 3. Blow-off valve

For leak sizing, the deflexions, obtained when the component and standard leak are probed, are compared. Provided the Pirani gauge responds linearly to a change in ressure, and the percentage of gas absorbed by the charcoal s constant for the ranges used, the size of leak is given by:

$$\text{standard leak} \times \frac{\text{component response}}{\text{standard leak response}}$$

EXPERIMENTAL RESULTS

Graphs showing the response to different leaks, and the esponses with different throttling of the outlet valve are hown in Figs. 4 and 5. The response is independent of the atio of pumping speed to volume, but the higher this ratio he quicker the response.

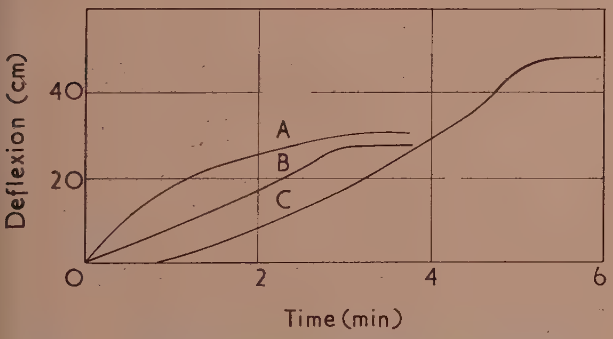


Fig. 4. Response of Pirani gauge to various leaks

A, a bellows leak 1·1 × 10^{-2} lμ/s; *B*, 10^{-2} lμ/s standard leak; *C*, 1·9 × 10^{-2} lμ/s leak on hard solder covered with sealing compound (long leak path).

In normal operation the deflexion is full scale 14 cm for a 0^{-2} lμ/s leak. Fluctuations are less than 1 mm and thus deflexion of 5 mm is considered adequate to prove a eak. Hence the smallest detectable leak is of the order of × 10^{-4} lμ/s.

THE LIFE AND ABSORPTION OF CHARCOAL

To predict the mass of charcoal suitable for a given leak detection problem, the total amount of air absorbed by the charcoal under flow conditions has been measured. With charcoal degassed at 200° C, 2 × 10^4 litre microns of air are absorbed for each cubic centimetre of charcoal present without any appreciable pressure rise on a McLeod gauge. However, results indicate that large variations are to be expected from different samples of charcoal; nevertheless, no variation has been detected between different batches of charcoal specifically treated for gas absorption, supplied by one manufacturer. The percentage absorption of hydrogen and air by charcoal depends on both flow rate and temperature. When the ratio of leak rate to volume of charcoal is 7 × 10^{-3} lμ per s per cm^3, 100% air and 74% hydrogen are absorbed at liquid nitrogen temperatures, whereas 63% air and 4% hydrogen are absorbed with solid carbon dioxide and trichlorethylene as coolant. If the ratio is 3 × 10^{-1} lμ per s per cm^3, 100% air and 30% hydrogen are absorbed with liquid nitrogen coolant whereas no air or hydrogen is absorbed with solid carbon dioxide and trichlorethylene as coolant. These figures show that a combination of solid carbon dioxide and trichlorethylene is a more satisfactory coolant for small leaks. In practice, if the component leakage must be less than 3 × 10^{-1} lμ/s for it to be acceptable, solid carbon dioxide and trichlorethylene are used together, if greater, liquid nitrogen. The charcoal can be degassed by removing the coolant and heating it to 200–300° C under vacuum.

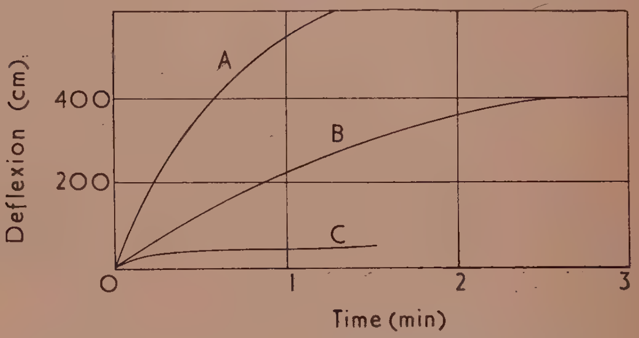


Fig. 5. Response of Pirani gauge with various positions of exit valve leak = 2 × 10^{-1} lμ/s

A, exit valve closed; *B*, exit valve open, quarter-turn; *C*, exit valve open, half-turn.

ALTERNATIVE METHODS OF OPERATION

Silica gel cooled with liquid nitrogen has been used successfully as an alternative to charcoal. Its advantage is that the fall in response is quicker when the hydrogen probe is removed from the leak. A disadvantage is that it requires degassing more frequently. Using a charcoal trap and Pirani gauge on the fine side of a unit with only one diffusion pump is satisfactory; the response is, however, slower. Satisfactory results have not been obtained using a rotary pump alone due to the high ultimate pressure of a rotary pump and pressure changes due to its mechanical action.

CONCLUSION

Since this work was completed, the technique has been used as a production method to vacuum-prove large numbers of components. In most cases the leaks could not be pinpointed without the use of a charcoal trap for several hours after initial pumping due to irregular pressure oscillation. Initially 20% of the components vacuum-tested by this method were checked by a static pressure rise method and no discrepancies found. Errors in leak comparisons are quite high as absorption is dependent on flow, but this is relatively unimportant. If, for example, large numbers of components are to be examined and rejected if their leak rate is greater than 10^{-2} lμ/s, the standard leak used will be 10^{-2} lμ/s. Only if the component response is less than the standard leak response will the component be acceptable for use.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. H. H. Heath for his hel throughout the course of this work, and the Managin Director, United Kingdom Atomic Energy Authorit (Industrial Group), for permission to publish.

REFERENCES

(1) Bleárs, J., and Leck, J. H. *Brit. J. Appl. Phys.*, **2**, p. 22 (1951).
(2) Clarke, D. *Department of Scientific and Industria Research Memorandum No.* 51 (17.4.1945).
(3) U.K. Patent Application No. 9312/53.

A voltage stabilizer for a radio-frequency extra high tension set

By R. B. D. Knight, B.A., K. M. Poole, M.A., D.Phil.,* and J. H. Sanders, M.A., D.Phil., A.Inst.P.,
The Clarendon Laboratory, University of Oxford

[*Paper first received* 7 *September, and in final form* 17 *November,* 1954]

An electronic voltage stabilizer capable of adaption to radio-frequency e.h.t. sets of any output voltage is described. Part of the e.h.t. output voltage is balanced against a reference voltage, any difference being amplified and used to control the screen voltage of the e.h.t. oscillator. An a.c. amplifier is used, d.c. voltage differences being changed to a.c. by an electronic converter and subsequently rectified.

The output voltage of a radio-frequency e.h.t. set may be controlled over a wide range by variation of the screen potential of the main oscillator valve. By using this method of control the use of a series or shunt valve(1) capable of withstanding large anode-cathode voltages is obviated. The stabilizer to be described has been applied to an e.h.t. set with an output capable of smooth variation over the range 5–20 kV. The block diagram (Fig. 1) shows the basis of the method. The fraction of the e.h.t. voltage appearing across *R* is balanced against a fixed reference voltage, any difference between them being converted to an a.c. signal in the electronic d.c.–a.c. converter. An electronic converter rather than a contact or capacitance-modulator(2) was chosen because it may be operated at the comparatively high frequency of 2 kc/s and so the whole system stabilizes against rapid fluctuations of the e.h.t. voltage. The a.c. signal is amplified by a tuned amplifier and is subsequently converted back to a d.c. signal at a phase-sensitive detector. This signal controls the screen potential of the main oscillator valve of the e.h.t. unit, and appears in the correct polarity to reduce the difference voltage at the converter. The use of a d.c.–a.c. converter eliminates the effect of drift inherent in a purel d.c. amplifier, and enables a high gain a.c. amplifier to b used. The only source of drift likely to be of consequenc in the circuit used is an unequal change in the characteristic of the two valves used in the converter stage itself.

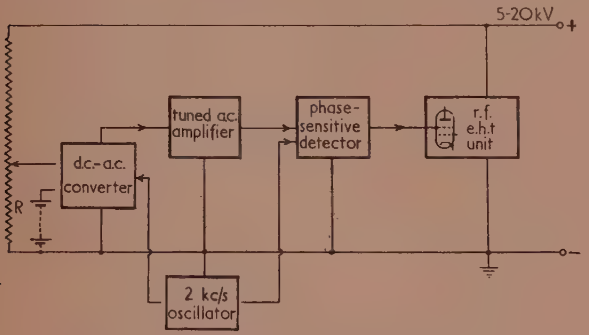


Fig. 1. Block diagram of the stabilizer system

CIRCUIT DETAILS

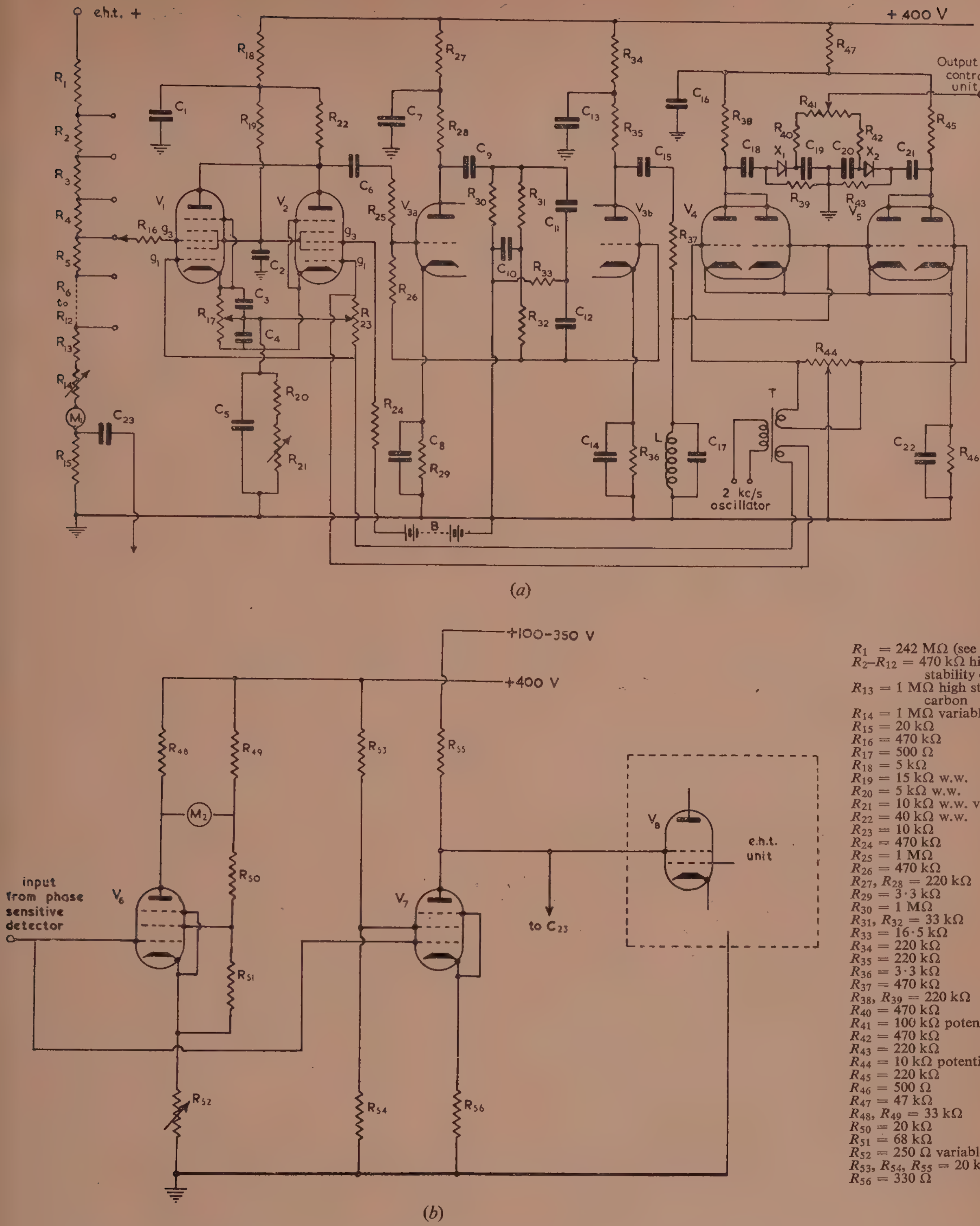
The circuit diagram of the stabilizer unit appears in Fig. 2 The 242 MΩ resistor R_1 is made up from 4·7 MΩ carbo resistors (Erie type 2) immersed in transformer oil, and give adequate stability of the e.h.t. output after an initial warming up period. Tappings on the resistor chain R_2 to R_{13} enabl the output voltage to be varied between 5 and 20 kV, variatio of R_{14} providing fine control. The microammeter M_1 indicate the e.h.t. voltage.

The converter stage consists of two pentagrid valves V_1 an V_2 with their anodes connected to a common load R_{22}. Th two grids g_1 are fed 180° out of phase with a constan amplitude 2 kc/s signal of about 2 V r.m.s. overall from th transformer *T*. When the a.c. currents passing through th two valves are equal, no 2 kc/s signal appears at their anodes, only a small even harmonic signal (mainly second) due t non-linearity of the valve characteristics. The 2 kc/s current passing through each valve are controlled by the potentia of grid g_3, which is connected in the case of V_1 to the tapping on the e.h.t. resistor chain and in the case of V_2 to the 120 V reference battery *B*. When the a.c. currents passed by th two valves are unequal, due to a change in potential of g_3 o V_1, a 2 kc/s signal appears across R_{22}. The phase of thi signal changes by 180° on passing through the balance point. The action of the stabilizer is to bring the a.c. currents passed by V_1 and V_2 close to equality.

The second harmonic signal across R_{22} is large enough t saturate the following stages, so is rejected by the combinatio of the twin-*T* network R_{31}, R_{32}, R_{33}, C_{10}, C_{11}, C_{12} and V_{3a} The output signal from the amplifier stage V_{3b} is broadl tuned to 2 kc/s by R_{37}, *L* and C_{17}. Valves V_4 and V_5, togethe with the crystal diodes X_1 and X_2 are connected as a phase-

---

* Now at Bell Telephone Laboratories, New Jersey, U.S.A.


e.h.t. +
+400 V
Output to control unit
R1
R2
R3
R4
R5
R6 to R12
R13
R14
M1
C23
R15
R16
g3
g1
V1
V2
R17
R18
R19
R20
R21
R22
R23
C1
C2
C3
C4
C5
C6
R24
R25
R26
R27
R28
R29
R30
R31
R32
R33
V3a
V3b
C7
C8
C9
C10
C11
C12
C13
C14
C15
C16
C17
R34
R35
R36
R37
B
L
T
2 kc/s oscillator
V4
V5
R38
R39
R40
R41
R42
R43
R44
R45
R46
R47
C18
C19
C20
C21
C22
X1
X2
+100-350 V
+400 V
R48
R49
M2
R50
R51
R52
R53
R54
R55
R56
input from phase sensitive detector
V6
V7
V8
to C23
e.h.t. unit

(*a*)

(*b*)

R_1 = 242 MΩ (see text)
R_2–R_{12} = 470 kΩ high stability carbon
R_{13} = 1 MΩ high stability carbon
R_{14} = 1 MΩ variable
R_{15} = 20 kΩ
R_{16} = 470 kΩ
R_{17} = 500 Ω
R_{18} = 5 kΩ
R_{19} = 15 kΩ w.w.
R_{20} = 5 kΩ w.w.
R_{21} = 10 kΩ w.w. variable
R_{22} = 40 kΩ w.w.
R_{23} = 10 kΩ
R_{24} = 470 kΩ
R_{25} = 1 MΩ
R_{26} = 470 kΩ
R_{27}, R_{28} = 220 kΩ
R_{29} = 3·3 kΩ
R_{30} = 1 MΩ
R_{31}, R_{32} = 33 kΩ
R_{33} = 16·5 kΩ
R_{34} = 220 kΩ
R_{35} = 220 kΩ
R_{36} = 3·3 kΩ
R_{37} = 470 kΩ
R_{38}, R_{39} = 220 kΩ
R_{40} = 470 kΩ
R_{41} = 100 kΩ potentiometer
R_{42} = 470 kΩ
R_{43} = 220 kΩ
R_{44} = 10 kΩ potentiometer
R_{45} = 220 kΩ
R_{46} = 500 Ω
R_{47} = 47 kΩ
R_{48}, R_{49} = 33 kΩ
R_{50} = 20 kΩ
R_{51} = 68 kΩ
R_{52} = 250 Ω variable
R_{53}, R_{54}, R_{55} = 20 kΩ
R_{56} = 330 Ω

C_1 = 8 μF
C_2 = 0·1 μF
C_3 = 20 μF
C_4 = 20 μF
C_5 = 8 μF
C_6 = 0·01 μF

C_7 = 8 μF
C_8 = 0·1 μF
C_9 = 0·01 μF
C_{10} = 2500 pF
C_{11}, C_{12} = 1250 pF
C_{13} = 8 μF

C_{14} = 0·1 μF
C_{15} = 0·01 μF
C_{16} = 8 μF
C_{17} = 0·016 μF
C_{18}–C_{21} = 0·1 μF

C_{22} = 20 μF
C_{23} = 0·5 μF

X_1, X_2 = CG1C

B = 120 V reference battery

L = 0·4 H dust core

T = Parmeko type AP54681

M_1 = 0–100 μA
M_2 = 2–0·2 mA

V_1, V_2 = 12SA7
V_3, V_4, V_5 = 12SL7
V_6, V_7 = 12SH7

Fig. 2. Circuit diagram of the stabilizer

(*a*) Converter, amplifier and phase-sensitive detector; (*b*) Valve voltmeter and final amplifier.

sensitive detector fed with a 2 kc/s reference signal of about 1·2 V r.m.s. overall from T. The phase-sensitive detector provides control voltages for the grids of V_6 and V_7. The latter controls the screen potential of the oscillator valve V_8 of the e.h.t. unit, model 105A (by Hivolt Ltd.), which is capable of supply voltages up to 30 kV. "Hunting" of the system as a whole (i.e. low-frequency oscillation about the stabilization point) is prevented by the degenerative loop provided by C_{23} and R_{15}. A valve voltmeter for monitoring the output of the phase-sensitive detector is formed by V_6 and M_2 and their associated circuit.

The power supply of the stabilizer is electronically voltage-stabilized throughout by conventional means and consists of two parts. One part gives a steady 400 V at 120 mA for the stabilizer and e.h.t. unit, plus a variable 100–350 V for the screen grid of the e.h.t. main oscillator. The other part gives 150 mA at approximately 100 V for the series-fed heaters of the valves in the stabilizer unit and in the power supply stabilizer. Stabilization of the heater supply in this way reduces considerably drift due to fluctuations of heater voltage with mains voltage. The 2 kc/s oscillator is of the conventional Wien-bridge type with thermistor control of the amplitude.

OPERATION

Initial adjustments consist of (*a*) adjusting V_1 and V_2 to a suitable working point by adjustment of R_{21}; (*b*) obtaining dynamic balance of the converter stage by variation of the tapping point on R_{17}; and (*c*) obtaining static and dynamic balance of the phase-sensitive detector by variation of R_{41} and R_{44} respectively. Tuning of the amplifier to obtain maximum gain at 2 kc/s and minimum at 4 kc/s may be done by adjustment of the appropriate component values.

The e.h.t. output voltage may be varied simply by altering R_{14} and the position of the tap on R_2–R_{12}, the stabilizer action being to change the output voltage accordingly. However, the stabilizer will not handle the full variation between 5 and 20 kV without saturation, so manual control of the screen supply voltage is provided. To bring the stabilizer to the centre of its working range at any e.h.t. voltage and load the screen supply voltage is adjusted until the meter M_2 gives a reading corresponding to zero output from the phase-sensitive detector.

PERFORMANCE

(*a*) *Variation of output voltage with mains supply voltage.* Typical curves, which were taken at 15 kV and loads of 100 μA and 400 μA, are shown in Fig. 3 (figures for load currents refer to currents drawn from the e.h.t. set in addition to the leak through the 250 MΩ resistor R_1–R_{15}). The rapid fall in output voltage below 220 V supply at 400 μA is due to saturation of the stabilizer unit at the point where the 400 V power supply stabilizer ceased to stabilize, and could be prevented by the provision of a more suitable power supply. Variations in the e.h.t. output were measured by means of a potentiometer, using a separate oil-immersed resistor chain for obtaining a suitable fraction (about 1 V) of the e.h.t. voltage for comparison with the e.m.f. of a standard cell.

(*b*) *Variation of output voltage with load.* When the e.h.t. unit is fed from a stabilized power supply, but is operated without the stabilizer described here, it shows an internal resistance of about 60 MΩ. With the stabilizer in operation the regulation is shown in Fig. 4, where curves are drawn at various nominal output voltages for loads up to 450 μA. The curves have been drawn through a common point at a load of 200 μA. The magnitude of the internal resistanc varies from zero to about 100 kΩ in the range shown.

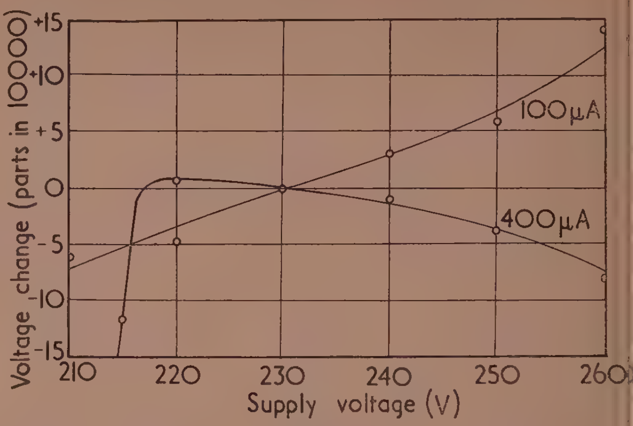


Fig. 3. Variation of output voltage with mains supply voltage

(Output voltage = 15 kV.)

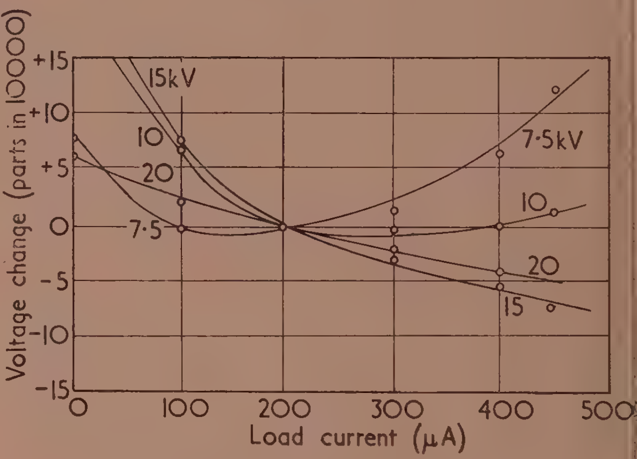


Fig. 4. Variation of output voltage with load

The reason for the appearance of a negative output resistance in the curve is not apparent from the simplified block diagram of Fig. 1, which is that of a proportional controller. Negative output resistance is of common occurrence in voltage stabilizers employing positive-feedback loops; in this case the positive feedback probably arises from the use of a common power supply, with finite internal resistance, for the e.h.t. unit and the screen of the control valve V_7.

(*c*) *Drift.* In the first two hours after switching on the e.h.t. voltage drifts by about 1 part in 100 under conditions of constant load and supply voltage. Subsequently the drift rate is less than 1 part in 1000 per hour, with short-term fluctuations of less than 1 part in 10 000.

(*d*) *Ripple.* The mains-frequency ripple voltage is almost independent of the output voltage, and rises from about 0·3 V r.m.s. at no load to about double this value at a load of 450 μA.

REFERENCES

(1) Benson, F. A. *Voltage Stabilizers*, pp. 78 and 96 (London: Electronic Engineering, 1950).

(2) Kandiah, K., and Brown, D. E. *J. Instn Elect. Engrs* **99**, p. 314 (1952).

The application of shearing interferometry to routine optical testing

By D. S. BROWN, M.A., Sir Howard Grubb, Parsons and Co., Newcastle upon Tyne

[*Paper received* 25 *November*, 1954]

Methods of interpretation of shearing interferograms, and the use of the interferogram height as a criterion of optical quality are considered. Two interferometers of simple design are described.

Wavefront shearing interferometry has not been very widely sed, as yet, in the testing of optical systems. The method as, however, certain advantages as a test of optical quality nd can also give, very easily, exact quantitative measurement f the wavefront form.

For small shears Drew(1) has shown that the interferogram eight is proportional to the wavefront slope. The wavefront orm may thus be calculated by a simple integration. For arger shears a similar method may be used in which a summation replaces the integration. Consider a set of points A, B, C . . . along a straight line on the wavefront, each paced $2s$ from the last. Shearing by $2s$ along this line each f the points will be sheared on to the next. Since the interferogram height is the difference of the sheared and unsheared wavefront heights, we have:

$$h_1 = h_A - h_B, \quad h_2 = h_B - h_C, \ldots$$

$$\textstyle\sum_n^1 h_n = h_A - h_N \tag{1}$$

where 1, 2, 3 . . . (Fig. 1) are points on the interference perture corresponding to A on B, B on C, etc., whilst h_1, h_2, h_A, h_B, are the interferogram and wavefront heights t the points indicated by the subscript. The height of each of the points B, C, D, . . . relative to A is now known. A uitable starting point may be the edge or centre of the wavefront aperture; the line of the points A, B . . . may conveniently be selected as the diameter parallel to the shear direction. f a single set of points does not give sufficiently full information, a second set of points may be measured. The problem f relating the two starting points then remains. Assuming he absence of a periodic error of period $2s$, the mean heights f the two point series may be equated. Alternatively, a econd interferogram with different shear may be used to elate the two starting points.

In cases where the expected form of the wavefront is known, s for a lens system with calculated aberration coefficients, an lternative approach may be used. For a wavefront of form $= x^n$ (n positive integer) we have, shearing by $2s$

$$h_1 = (x_1 + s)^n - (x_1 - s)^n$$

$$h_1 = 2[{}_nC_1 x_1^{(n-1)} s + {}_nC_3 x_1^{(n-3)} s^3 + . + . + (+s^n \text{ if } n \text{ odd})] \tag{2}$$

where ${}_nC_1$, etc., are the usual binomial coefficients.

The following table illustrates a few common cases:

h_1	*Aberration*
$4x_1s$	defocusing and astigmatism.
$6x_1^2s + 2s^3$	primary coma.
$8x_1^3s + 8x_1s^3$	spherical aberration.
$10x_1^4s + 20x_1^2s^3 + 2s^5$	higher coma.
$12x_1^5s + 40x_1^3s^3 + 12x_1s^5$	higher axial.

From equation (2) it may be seen that higher powers of x hear to odd or even power series, the highest power being one less than the original power. A convenient method of eduction is to measure h_1 at a number of points, dependent on the expected wavefront form, and express the interferogram height as a polynomial, from which the wavefront polynomial is derived. The highest term should be dealt with first, as the value of this coefficient will affect the lower terms. The odd and even terms are perhaps better separated before reduction.

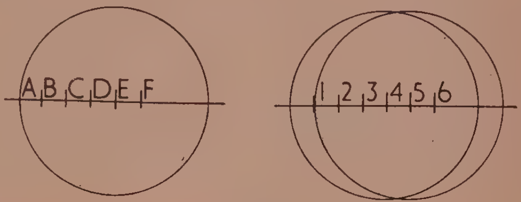


Fig. 1

Apart from the use of shearing interferometry to determine wavefront form, the method may be employed without reduction to give an index of "optical quality." It is clear that where small shear reduction may be employed a relation between image width and interferogram height will exist. It is most useful, perhaps, to put this in the form

$$W_m = D_m/2\alpha \tag{3}$$

where W_m is the maximum image width, D_m is the maximum interferogram height and 2α the angular shear. It has been found experimentally that the equation (3) gives good results, even when the shear is larger than would be considered valid for a small shear interpretation, provided that the values of D_m are not too large (two or three wavelengths). Further work on this will be necessary to establish the relation on a sound theoretical basis, but it would appear that a criterion of optical quality based on W_m determined either with small shear or with D_m restricted to values of less than 2λ, could be valuable. Alternatively, a selected tolerance D_1 may be used, and the areas of the interference aperture with heights greater and less than D_1 taken as proportional to the light intensity inside and outside the associated image width W_1. This approach has been found useful in comparing the performance of lens systems where the desired resolution is known. Both this method and the measurement of W_m by the relation (3) have been found to give consistent data for the assessment of optical performance. The values of W found in this way refer to the width of the image of a line source. To make the method sensitive to astigmatism a second interferogram with shear perpendicular to the original shear direction and taken at the same focus may be required.(2)

Apart from the question of interpretation of shearing interferograms, the main obstacle in the path of the intending user of the shearing technique has been the interferometer itself. The instrument described by Bates(3) is extremely flexible, but is not suitable for routine testing work. The simpler design of Drew(1) is much easier to use, but it cannot be relied on to remain in adjustment, with the degree of accuracy required for the testing of wide-angle cones, over long periods of time. Re-adjustment with zero shear is not difficult, but can be the cause of some inconvenience. The desirable features in a shearing interferometer for workshop use are: (1) mechanical and optical reliability; (2) simplicity of operation; (3) reasonably small size; (4) independent, continuously variable controls. The cemented units described by the author$^{(2)}$ meet the first three of these requirements, but since both shear and tilt are fixed, the range of testing for which a single unit may be used is limited. A family of shearing interferometers exists having certain advantages over previous designs, and with suitable mechanical construction they may easily be made suitable for routine testing.

In his paper, Drew$^{(1)}$ noted the resemblance of his instrument to that of Mach and Zehnder. The Bates instrument may, broadly speaking, be placed in the same category. Bearing in mind the greater simplicity of the Jamin interferometer compared with the Mach–Zehnder instrument, the possibility of designing shearing interferometers related to the former was considered.

Two designs evolved from this investigation and others are undoubtedly possible. The first type uses a small angle prism to introduce shear and suffers, in consequence, from certain disadvantages. The second has shear introduced at a reflecting surface but is slightly more complex. Figs. 2 and 3 show the two instruments.

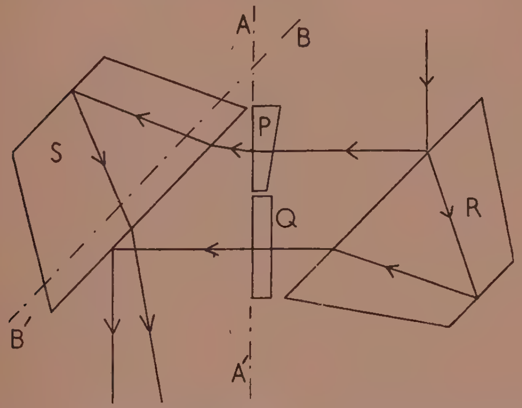


Fig. 2. Optical arrangement of shearing interferometer, refracting type

The instrument shown in Fig. 2 consists of a normal Jamin interferometer used in convergent light; into it is introduced a prism *P* and a compensating plane parallel *Q*, the prism being situated at the focus of the wavefront under test. Tilt between the sheared and unsheared wavefronts may be introduced either by a slight rotation of *Q* about the axis *A*–*A*^{1} or by rotation of the second interferometer plate *S* about the axis *B*–*B*^{1}. In the latter case the fringe pattern will have a slight lack of compensation, similar to that found in the Drew instrument.$^{(1)}$ The second method has the advantage that *P* and *Q* may be fixed to a single metal frame which may be made detachable so that prisms giving different shears may be used. For correct compensation the faces of *P* and *Q* facing *S* should lie in the same plane. The use of a prism to introduce shear is open to objection on two accounts. Firstly, the variation of shear with wavelength; secondly, the variation of shear across the field of view. Neither of these defects is very troublesome unless highly aspheric wavefronts are to be investigated.

The mechanical construction of this instrument may be very simple. In the prototype each of the glass plates *R* and *S* is mounted on a triangular metal plate. The plate carrying *S* has two steel balls on its lower surface, each of which rests in a hollow in the main base of the instrument. The line of centres of the steel balls is parallel to the faces of *S* and the third support of the unit is a screw passing through a tapped hole in the plate. The screw forms the tilt control of the instrument. The plate bearing *R* is fixed to the main base by a single screw passing through the base into the plate. After initial adjustment of *R* and *S* for parallelism this screw is tightened to lock *R* in position. A set of interchangeable metal frames, each carrying a prism and plane parallel, is used to give different values of the shear.

The second instrument shown in Fig. 3 uses a thick plate and its mirror image in place of the two plates of the previous instrument. By "breaking" the mirror in which this imaging is performed, and rotating one-half (*L*), shear is introduced. By a slight rotation of the plate *O* about an axis *C*–*C*′, tilt between the sheared and unsheared wavefronts is introduced. For convenience in use a mirror *M* may be used, to make the incident and emerging rays approximately parallel.

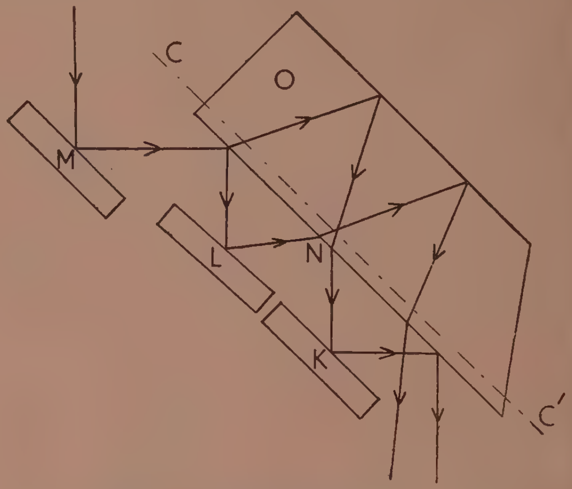


Fig. 3. Optical arrangement of shearing interferometer, reflecting type

The mechanical construction of this instrument may also be made relatively simple. Fig. 4 shows an exploded view of the construction used for the prototype. The back plate *T* and the spacer *U* have holes for the two control screws, those in the spacer being tapped. Both *T* and *U* are screwed

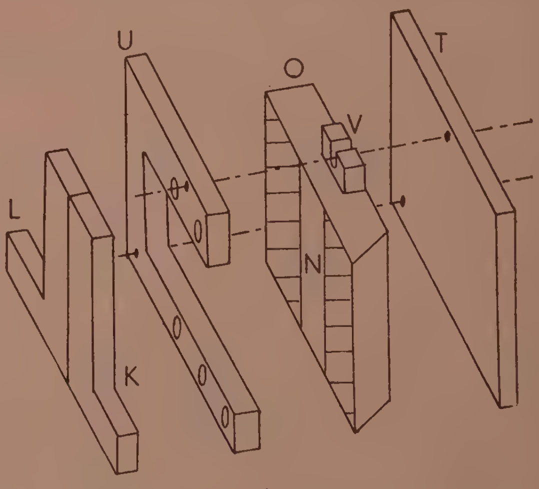


Fig. 4. Exploded view of reflecting type instrument

o a metal base. The spacer *U* carries five selected steel balls cemented into it so that their centres are co-planar. When assembled, the mirror *K* rests against three of these balls and *L* against the other two and the shear control screw. n the zero tilt position *O* contacts all five balls, but when ilt is introduced it is pulled away from the two upper ones. This is effected by means of a shoulder on the tilt screw ngaging on the face of a metal block *V* cemented to the upper edge of *O*. Rubber pressure pads between *O* and *T* and between the outer wall of the instrument and *K* and *L* maintain the optical parts in contact with the spacer *U*. In order to suppress unwanted reflexions in the instrument it is desirable that the face of *O* towards the spacer should be semi-reflecting, except for a strip in the region of *N* which should be bloomed. The semi-reflecting layer in the prototype consists of a triple dielectric layer, one component of which extends to form the anti-reflecting coating at *N*.

In both the instruments, fringe visibility is controlled by a relative rotation of slit image and interferometer about the optic axis of the system under test. Path length equalization within the instrument is obtained by a relative movement of slit image and interferometer in the shear direction. The second instrument has completely independent controls which may both be operated without loss of fringe visibility. The tilt control on the refracting shear instrument may also be operated without loss of fringe visibility. Both instruments will accept cones of up to $f/3$ aperture.

Both types of instrument have been found to remain in adjustment over a period of several months of intermittent use and, whilst not quite as simple to operate as fixed shear and tilt instruments, they have been found quite suitable for routine workshop testing.

REFERENCES

(1) Drew, R. L. *Proc. Phys. Soc.* [*London*] *B*, **64**, p. 1005 (1951).

(2) Brown, D. *Proc. Phys. Soc.* [*London*] *B*, **67**, p. 232 (1954).

(3) Bates, W. J. *Proc. Phys. Soc.* [*London*], **59**, p. 940 (1947).

An isothermal bath for use in the temperature range 200–500°C

By W. H. Bridges, B.S., J. V. Cathcart, Ph.D., and G. P. Smith, Ph.D., Metallurgy Division,
Oak Ridge National Laboratory, Tennessee, U.S.A.

[*Paper received* 6 *September*, 1954]

A constant-temperature bath having excellent control and stability characteristics has been constructed. A molten 50–50 wt % mixture of sodium nitrate and sodium nitrite, vigorously stirred, was used as the bath liquid. An electronically balanced Wheatstone bridge, operated in conjunction with a platinum resistance thermometer, controlled the bath temperature; a second resistance thermometer served to monitor the temperature. Temperature fluctuations of ±0·025° C at 400° C were observed over a period of 500 h, but control to ±0·01° C could be attained for shorter periods of time.

A constant temperature bath was constructed in which emperature control to ±0·025° C at 400° C for periods as ong as 500 h was attained. When it is desired to carry out a reaction under precise isothermal conditions, it has long been common practice to utilize a liquid constant temperature bath.⁽¹⁾ Such a bath combines a relatively high heat capacity with the ability to distribute heat evenly to all parts of a complex reaction vessel. Thermal fluctuations and temperaure gradients can easily be minimized by vigorous stirring of he liquid, and, provided the range of operation is below 150–200° C, very satisfactory temperature control can be attained with an inexpensive mercury thermo-regulator or some comparable control instruments. At higher temperaures, however, although a liquid bath still provides a very desirable uniform distribution of heat and relatively small hermal gradients, accurate temperature control becomes a much more complex problem.

These difficulties have been overcome in the constant emperature bath described below. By using a molten salt as the bath liquid, it was possible to retain the advantages of he low temperature baths and at the same time achieve precision temperature control. A survey of the literature has revealed no other bath for operating the temperature range 200–500° C which has comparable control and stability.

The apparatus consisted essentially of three parts: a molten salt bath, a temperature control system, and a temperature monitoring system.

THE SALT BATH

The bath consisted of a molten 50–50 wt % mixture of sodium nitrate and sodium nitrite. The mixture had a melting point of approximately 150° C and a satisfactorily low viscosity in the temperature range of 200–500° C. The salt was contained in a stainless steel pot 10 in. in diameter and 17 in. deep. The bath was surrounded in all directions, except the top, by 10 in. of commercial rockwool contained in a large steel cylinder. About 2000 W of heat were supplied to the bath by directly immersed, stainless steel-sheathed, heater elements of the low-lag type. To avoid high heat loss from the top, a tight-fitting cover was made and provided with a removable section through which the apparatus could be inserted into the bath. Vigorous agitation of the bath was found necessary in order to maintain acceptable temperature control. A stirrer with a three-bladed impeller 2·5 in. in diameter, turning at approximately 800 rev/min, was satisfactory for this purpose. In order to minimize vortex formation in the bath a flat plate, 2·5 in. in diameter, was attached to the stirrer shaft just above the impeller.

The maximum temperature at which a sodium nitrate-sodium nitrite bath can be operated conveniently is approximately 500° C. Above this temperature both evaporation and decomposition become serious. The nitrate-nitrite mixture does, however, possess the advantage of having a comparatively slight corrosive effect on Pyrex glass, and it was largely for this reason that the above bath composition was selected. There appears to be no reason, provided a suitable salt(2) is chosen, that the temperature control equipment described in this paper could not be used at temperatures considerably higher than 500° C.

THE CONTROL SYSTEM

The control system was built about a high-precision resistance-thermometer recorder. The instrument was essentially an electronically-balanced Wheatstone bridge with thermostatically controlled measuring-bridge resistors. The span of the instrument was 1·01 Ω, but an automatic range-changing device increased the scale to 100 Ω in 1 Ω increments. The sensing element used in connexion with this controller was a precision platinum resistance thermometer.

Operating in conjunction with the measuring bridge was an electric control unit of the duration-adjusting type. This unit varied the power fed to the heaters by turning the current on and off for time intervals, the duration of which was proportional to the deviation of temperature from the control point. At the control point, the ratio of on- to off-time was approximately unity. When the temperature dropped below the control point, the ratio of on- to off-time increased, and when the temperature rose above the control point, the ratio decreased. Although the temperature fluctuation produced in the bath over long periods amounted to ±0·025° C at 400° C, the system was capable of controlling to ±0·01° C at 400° C for times up to about twelve hours.

Both long range and short range thermal cycling were observed in the bath. The short range cycle had a period of about five minutes, and the accompanying temperature change was ±0·01° C. The long range cycling was probably associated with changes in line voltage which occurred at the beginning and at the end of the day. The resultant temperature changes were approximately ±0·02° C. Small thermal gradients were also observed in the bath. The gradients were stable and their existence had no measurable effect on the degree of control attainable in the system. The pattern of isothermal lines in the bath was rather complex; however, the coolest regions were near liquid-air interface. A small horizontal gradient also existed, the centre portion of the bath being slightly cooler than the sides. The temperature difference between any two points in the bath was no greater than 0·15° C, and the temperature difference between any two points in a region extending from about six inches below the surface to the bottom of the bath was no more than 0·05° C.

THE TEMPERATURE MONITORING SYSTEM

The temperature monitoring system had four components: a platinum resistance thermometer, a Mueller bridge, a microvolt amplifier, and a recorder. A resistance thermometer similar to that used in the control circuit was also employed in the monitoring circuit. The thermometer was calibrated by the National Bureau of Standards and was capable of measuring temperatures to ±0·005° C. The thermometer was connected to a Mueller bridge which had also been calibrated by the National Bureau of Standards. The bridge was sufficiently sensitive to measure a resistance or change in resistance to at least two parts in 10^5. The bridge was operated continuously in a slightly unbalanced condition. In place of the usual galvanometer, a stabilized d.c. microvolt amplifier was used. The amplifier was a high-gain, low-level electronic instrument with a sensitivity of at least one microvolt. The output of the amplifier was fed into a recorder. At the lowest scale range, full scale on the recorder was equivalent to 0·145° C. The entire system was checked against a standard resistor for long-time stability and was found to be stable well within the limits of error for each component. An overall precision of 0·0005% was attained with this arrangement over periods of time in excess of 500 hours.

The use of separate systems for monitoring and controlling the temperature of the bath had several advantages. A much greater sensitivity was achieved in the temperature recorder than was possible with the controller alone. Any change in the calibration of either the control or monitoring thermometer could be detected immediately by a comparison of the two recorder charts. Such a check would also show any instability in either the control or monitoring instruments.

Several types of resistance thermometers, in addition to the precision laboratory model described above, were tested in the salt bath. An attempt was made to use a platinum resistance thermometer in which the resistance element was fused into a quartz protection tube. It proved to be unsatisfactory in that it lacked sufficient stability to maintain the desired temperature control. The instability was attributed to small strains set up in the resistance element as a result of the difference in the thermal coefficients of expansion of the quartz and platinum. A thermometer with an uncoiled platinum wire wound on a mica support was also used as the monitoring thermometer. Satisfactory performance was obtained from this instrument; however, the vigorous stirring required in the bath tended to set up vibrations in the mica core which eventually caused the mica to crumble and the wires of the resistance element to short. Similar difficulties were experienced with the precision, laboratory-type thermometer in which the resistance element was wound in the form of a helix and then coiled about a mica support. Limited tests have been made with an industrial-type resistance thermometer. In this instrument the resistance element was wound on a ceramic core, the entire element then being packed in aluminium oxide powder. Good results have been obtained with this thermometer, and it may prove to be the best instrument for use in a salt bath of the type described here.

In the early stages of the development of the bath, an attempt was made to use thermocouples as temperature sensing elements for the bath. The control circuit consisted of an electronic controller-recorder, operating in conjunction with a duration-adjusting type electric control unit. Using chromel-alumel thermocouples, temperature control on the order of ±0·5° C was obtained at 400° C. In addition to the fact that the control circuit was inherently less sensitive than that used with the resistance thermometers, the temperature control obtainable was limited by erratic changes in thermocouple calibrations due to the presence of strains and inhomogeneities in the thermocouple wires. It is believed that a definite improvement in the temperature control could have been attained by the use of carefully annealed platinum/platinum-rhodium thermocouples. However, because of the comparatively small temperature coefficient of platinum thermocouples, the degree of control thus obtained would still not have been equal to that given by the resistance thermometers.

REFERENCES

(1) Grace, A., and Hall, J. A. *J. Sci. Instrum.*, **20**, p. 60 (1943).

(2) Lyman, T. (Ed.). *Metals Handbook*, pp. 283–291 (Cleveland, Ohio: American Society for Metals, 1948).

A sensitive wave-front tilter

By M. De, M.Sc., Imperial College of Science and Technology, London

[*Paper first received* 6 *October, and in final form* 5 *November*, 1954]

The possibility of using rotation of a small angle prism for the purpose of tilting plane waves has been investigated. It is found that this provides a very useful method of tilting plane waves by amounts of the order of a second, where the conventional methods fail to possess either reproducibility or precision.

xisting methods for calculating the diffraction image roduced by a non-spherical converging wave-front are mpracticable. Moreover, the conventional methods of neasuring the intensity distribution in a diffraction pattern, or example, by scanning the image using a pinhole aperture, re subject to obvious limitations. A proposal to use a wave-ront tilting interferometer has made possible a new approach o the problem. In this instrument an aberrated wave merging from a lens system is made to interfere with a ilted unaberrated reference wave. It can be shown that the otal light flux in the interference pattern will give a measure f the amplitude in the diffraction pattern associated with he aberrated wave, for a point determined by the direction f propagation of the unaberrated wave relative to that of he aberrated wave. Thus, by changing the angle of tilt of he reference wave with respect to the wave-front under test, he whole diffraction pattern can be scanned. It so happens hat a total range of about 30″ for the tilt of the un-berrated wave is required to cover a sufficiently wide part f the diffraction pattern, and also the tilt should be variable n steps of at least 1″ to get a sufficient number of neasurements over the total range.

Evidently the success of this method of measuring the iffraction pattern depends almost entirely on the precision, neasurability and reproducibility of the mechanism producing he tilt of the reference wave-front. These requirements are uch that the conventional methods are inadequate. Neither divided circle nor a plane mirror can be rotated with dequate accuracy, and the device utilizing an oppositely otating pair of thin wedges requires prisms of such small ngle as to be incapable of accurate production, the angle eing, indeed, comparable with the tolerances in manufacture.

The possibility of satisfying these conditions had to be ooked for elsewhere. It is commonly supposed that the eviation by thin wedge is constant and independent of the ngle of incidence. The fact that this is not so offers a ossibility of rotation of a thin prism being utilized for the urpose under consideration. When the wedge angles are of he order of 2–6° the rate of change of deviation with angle f incidence is sufficiently slow to make a relatively large hange in the angle of incidence necessary in order to produce he smallest necessary change in deviation.

The equations of refraction by a prism are as follows:

$$\left.\begin{aligned} \sin i_1 &= \mu \sin i_1' \\ A - i_1' &= i_2' \\ \mu \sin i_2' &= \sin i_2 \\ i_1 + i_2 - A &= D \end{aligned}\right\} \qquad (1)$$

here i_1, i_1' are the angles of incidence and refraction at the irst surface, i_2, i_2' are the angles of emergence and incidence t the second surface, μ the refractive index of the material f the prism of angle A and D is the deviation produced. rom these equations it can be shown that

$$\delta D = \left(1 - \frac{\cos i_1 \cos i_2'}{\cos i_2 \cos i_1'}\right).\delta i_1 \qquad (2)$$

The desired condition is to produce δD of the order of 0·000003 radian by a sufficiently large value of δi_1, so that any reasonably precise mechanical device may be utilized. Assuming $\delta i_1 = 0{\cdot}002$ radian to be quite reasonable, $\delta D/\delta i_1$ should be of the order of 0·0015 radian in magnitude. Remembering that $\delta D/\delta i_1$ is a negative quantity, we have the condition that

$$\frac{\cos i_1 \cos i_2'}{\cos i_1' \cos i_2} = 1{\cdot}0015$$

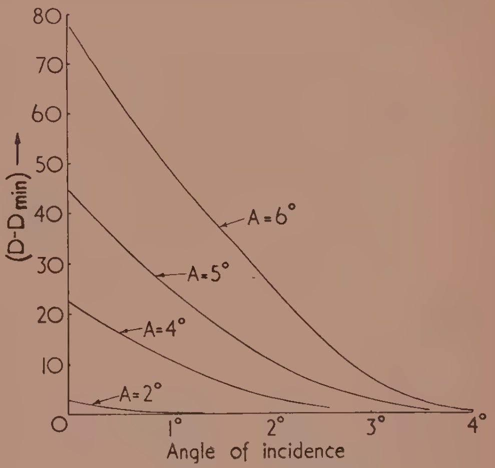
Since the rate of change of deviation is zero at the minimum deviation position, the above condition must necessarily be realized at a position away from that of minimum deviation.

Thus taking $i_1 = i_1' = 0$, or in other words with the light incident normally on the first face, the condition reduces to

$$\frac{\cos i_2'}{\cos i_2} = \sqrt{\left(\frac{1 - \sin^2 A}{1 - \mu^2 \sin^2 A}\right)} = 1{\cdot}0015$$

Assuming $\mu = 1{\cdot}55$, A becomes equal to 2° 40′, which is of reasonable magnitude, since wedges of such an angle can be satisfactorily produced within an error of less than 1%.

The other condition to be satisfied is to cover the full range of change in deviation to be produced. To check this, calculations were done for prisms with angles of 2, 4, 5 and 6° with $\mu = 1{\cdot}612$, using six-figure accuracy. Noting the very small number of steps for each calculation, the total absolute error in the final result can hardly exceed a second. The final results are shown in the figure. It will be seen that with a 4° prism, a change in the angle of incidence of 30′ near normal incidence on the first face brings about a change in deviation of 7″, so that the reduction ratio is of the order of 260 : 1 and is still quite satisfactory. The reduction ratio increases as the prism is rotated towards the minimum deviation position.



Change in deviation by small angle prisms

Evidently the range of total change in deviation and with the desirable maximum value of $\delta D/\delta i_1$ depends not only on the prism angle A, but also on the refractive index. The effect of variation of μ on the change of deviation has also been studied. For a prism having an angle of 4° and a refractive index of $1{\cdot}5$ the minimum deviation is 2° 00′ 05″, compared with a minimum deviation of 2° 27′ 00″ for a prism of the same angle with a refractive index of $\mu = 1{\cdot}612$. The change in refractive index by $0{\cdot}112$ changes the deviation by about 26′ 55″. This, therefore, gives an indication of the possibility of using a small angle prism of material, the refractive index of which can be varied precisely by small amounts. Thus, if the pressure of a gas can be precisely controlled to within $0{\cdot}1$ mm of mercury, the refractive index can be made to vary by a few units in the fifth decimal place thus allowing a change in deviation of the order of a second. Further, since $(\mu - 1)/\rho$ is constant for a gas of refractive index μ at a density ρ, there is approximately a linear relationship between the change in refractive index and the change in density or pressure of the gas, provided there no large change in the latter.

The small angle prism could be usefully employed i measuring very small angular movements. Any small angula movement can be converted into a corresponding angula tilt of a plane wave, which, with a simple form of inte ferometric device may be neutralized by the rotation of th prism in the path of the tilted plane wave. A high magnifica tion of the initial small angular movement is thus obtainabl which could be directly read off from the previously calibrate interferometric device.

ACKNOWLEDGEMENTS

I wish to thank Dr. H. H. Hopkins for helpful discussio concerning this work and the main problem. Thanks ar also due to the Government of India and the University o Calcutta for the provision of a maintenance grant.

Photoconductive detectors for infra-red spectroscopy

By A. S. Young, Radar Research Establishment, Malvern, Worcs.

[*Paper received* 24 *December*, 1954]

A method of constructing lead telluride infra-red photoconductive cells, sensitive at liquid oxygen temperature, is described. Details are given of the performance of the cells when used as detectors in infra-red spectrometers.

The development of sensitive photoconductive layers of lead selenide(1,2,3) and lead telluride,(4,5) has been announced in the literature by a number of workers, but few details of constructional methods and cell performance have been given. The following note describes a method, successfully used at this Establishment, to make layers of lead telluride of high sensitivity when cooled to liquid oxygen temperature.

These lead telluride cells have now been used by a number of spectroscopists for the past few years to obtain greatly increased sensitivity, particularly in the range $3{\cdot}5$–$5\ \mu$. Typical examples of their use to obtain high resolution infra-red spectra are given by Thompson and Williams,(6) and by Boyd and Thompson.(7) Their extremely rapid response has also enabled them to be used in high-speed recording spectrometers.(8) The lead selenide cells have enabled these advantages to be extended to a wavelength of about $7\ \mu$; high resolution spectra in this extended range are given by Roberts and Young.(9) The properties of the cells have been briefly described by Smith(10) but, so far, no details of their construction, and only qualitative data on their performance, have been published. The present paper gives details of a method of making the cells, successfully used by the author, and also describes some measurements of their characteristics.

CELL CONSTRUCTION

In the construction of these cells use is made of a double-walled hard-glass Dewar cell. This allows for the cooling of the layer with a liquid refrigerant. The cells can either take the form as shown in Fig. 1, with the "window" sealed in the end position, or can be so constructed that the window is sealed in the side of the cell blank. With the former type of cell it is usually necessary to use a plain mirror at 45° in order that the cell, when filled with the refrigerant, will remain vertical. The windows used in these cells must be capable of transmitting the radiation to which the cells are sensitive. For a lead telluride cell the "window" used is artificial sapphire (Al_2O_3) with a transmission of 50% at $6{\cdot}2\ \mu$. Methods of making vacuum-tight heat-resisting seals between the windows and the cells have been discussed by Young and others.(11,12) The connexions to the photoconductive layer are made by means of two tungsten leads and graphite electrodes, the electrode configuration being arranged to suit the output of a spectrometer, being normally of dimensions 1 cm × 1 mm.

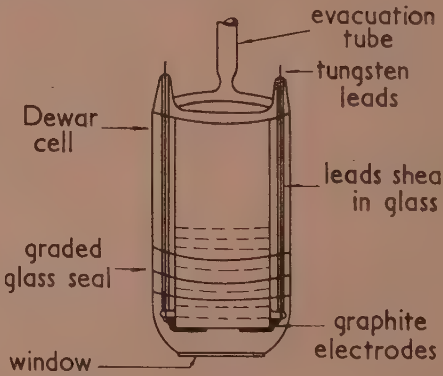


Fig. 1. Diagram of cell construction. Actual size of cell 3 × 1¼ in. diameter

PREPARATION OF LAYERS

The evaporated layers are made in the following manner. The starting materials are prepared by fusing together stoichiometric quantities of the elements in a quartz tube, al precautions being taken to keep the compound as pure as possible. About 3 mg of the powdered material is inserted into the cell blank which is in turn sealed to a vacuum system The vacuum system is constructed of hard glass with a mercury diffusion pump and liquid-air traps capable of attaining a pressure of 10^{-6} mm of mercury. Suitable taps and means of producing oxygen gas are also available.

The cell is evacuated until a pressure of 10^{-6} mm o mercury is reached, during which time it is outgassed a about 350° C for a few minutes. It is then heated in ar ectrically-controlled oven to 580° C, at which temperature ne lead salt evaporates readily. By cooling the window of ne cell with compressed air, a film is condensed on the inside, ne oven being switched off after sufficient material has been ollected. The cell is now isolated from the mercury pump nd a low pressure of oxygen of the order of 10^{-2}–10^{-3} mm f mercury introduced. The condensed film is then transerred, through this low pressure of oxygen, by heating the ront window with a gas-air flame, the material condensing n the electrode surface, which has been kept at a low temperaure. The cell is evacuated and the layer sensitized by heating n a vacuum. Sensitivity measurements are carried out while ne cell is still attached to the vacuum system by means of a ortable black-body and amplifier. Measurements of the pectral response can also be carried out at this stage by neans of a double-prism Leiss monochromator.(13) When ensitized, the cell is sealed off from the vacuum system and then ready for use.

SENSITIVITY MEASUREMENTS

Some measurements of the sensitivity were made using a lack-body source at 200° C, the temperature being conrolled to $\pm\frac{1}{4}$° C. The radiation was chopped at 800 c/s and mplified with a tuned amplifier.(14)

Details of the black-body source are as follows: temperature f black-body, 200° C; diameter of aperture, 3 mm; distance f cell from aperture, 20 cm; chopping frequency, 800 c/s; mplifier bandwidth, 50 c/s. The flux density from the blackody at 20 cm = $13 \cdot 6 \times 10^{-6}$ W/cm^2.

Absolute measurements of the sensitivity at a spot frequency ere also made by means of an approximately monochromatic ne source at a wavelength of 2 μ. This monochromatic adiation was obtained from a double monochromator using uartz prisms and a tungsten lamp source. The flux at 0 cm from the exit slit was adjusted to be $13 \cdot 6 \times 10^{-6}$ W/cm^2 nder which conditions the wavelength bandwidth at 2 μ as 0·03 μ. The radiation in this instance was also chopped t 800 c/s. Readings of signal-to-noise ratio with various urrents through the cell were taken using both sets of test quipment in order to determine optimum operating conitions. Absolute sensitivity at other wavelengths was educed from the spectral response of the cell.

TIME CONSTANT

Measurements of the time constant were carried out using pulsed neon source and cathode-ray tube display unit. his equipment was not suitable for very short time constants, lower limit being approximately 10 μs.

SPECTRAL RESPONSE

The spectral response curves of the cells were obtained by sing a constant energy monochromator designed and onstructed in the laboratory.(15) Typical curves are shown Figs. 2 and 3.

A considerable number of these lead telluride cells have ow been made at and used at this laboratory, and have also een used by a number of other workers for obtaining high esolution infra-red spectra. The average value of the inimum detectable power with a 1 c/s bandwidth at the eak of the spectral response for these cells is about $\times 10^{-11}$ W. With a sensitive area of 0·1 cm^2 this correponds to a minimum detectable flux of 2×10^{-10} W/cm^2. his represents a considerable improvement in sensitivity ver an average thermocouple. The resistance of the cells aries between 20 and 100 MΩ under operating conditions and the time constant between 20 and 40 μs. These values are for a layer temperature of about −183° C at which the cells are normally operated.

A few lead selenide cells have also been made in this way and supplied to a number of spectroscopists. Operated at −183° C they extend the photoconductive spectrum to about 7 μ but their maximum sensitivity is only about five times that obtainable from an average thermocouple.(9) Their short-time constant is, however, of considerable advantage for use in scanning spectrometers as has been shown by Roberts and Young.(9)

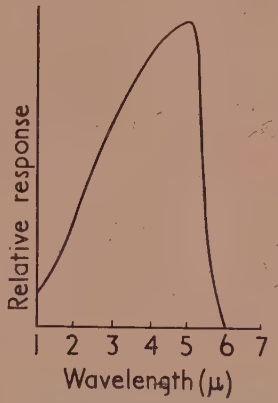


Fig. 2. Spectral response of a lead telluride cell at −183° C

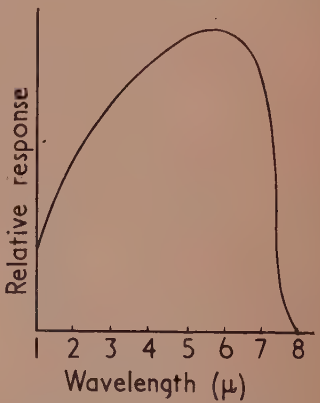


Fig. 3. Spectral response of a lead selenide cell at −183° C

ACKNOWLEDGEMENTS

Thanks are due to Mr. W. H. E. Wilgoss and Mr. A. A. Brooker of this laboratory who have made a number of the cells and assisted in the measurements.

Acknowledgement is made to the Chief Scientist, Ministry of Supply, for permission to publish this paper. Crown copyright reserved; reproduced by permission of the Controller of H.M. Stationery Office.

REFERENCES

(1) Simpson, O. *Nature* [*London*], **160**, p. 791 (1947).
(2) Moss, T. S., and Chasmar, R. P. *Nature* [*London*], **161**, p. 244 (1948).
(3) Gibson, A. F., Lawson, W. D., and Moss, T. S. *Proc. Phys. Soc.* [*London*] *A*, **64**, p. 1054 (1951).
(4) Simpson, O., Sutherland, G. B. B. M., and Blackwell, D. E. *Nature* [*London*], **161**, p. 281 (1948).
(5) Moss, T. S. *Nature* [*London*], **161**, p. 766 (1948).
(6) Thompson, H. W., and Williams, R. L. *Trans Faraday Soc.*, **48**, p. 502 (1952).
(7) Boyd, D. R. J., and Thompson, H. W. *Trans Faraday Soc.*, **48**, p. 493 (1952).
(8) Brown, D. A. H., and Roberts, V. *J. Sci. Instrum.*, **30**, p. 5 (1953).
(9) Roberts, V., and Young, A. S. *J. Sci. Instrum.*, **30**, p. 199 (1953).
(10) Smith, R. A. *Adv. Phys.*, **2**, p. 321 (1953).
(11) Chasmar, R. P., Craston, J. L., Isaacs, G., and Young, A. S. *J. Sci. Instrum.*, **28**, p. 206 (1951).
(12) Young, A. S. *J. Sci. Instrum.*, **28**, p. 207 (1951).
(13) Roberts, V. *J. Sci. Instrum.*, **29**, p. 134 (1952).
(14) Brown, D. A. H. *J. Sci. Instrum.*, **29**, p. 292 (1952).
(15) Avery, D. G., and Hammond, P. H. *J. Sci. Instrum.*, **30**, p. 400 (1953).

A modified pocket integrating ion chamber type B.D.11 of nearly uniform polar response

By B. W. Soole, A.R.C.S., Ph.D., A.Inst.P., Admiralty Research Laboratory, Teddington, Middlesex

[*Paper received* 9 *December*, 1954]

The pocket ionization chamber type B.D.11 as developed by the Medical Research Council for personnel protection is shown to be less sensitive to γ-radiation received along its axis than to radiation received in a perpendicular direction. By reducing the overall length of the chamber from 46·5 to 32·5 mm the chamber may be made equally sensitive in all directions, excepting that along its axis through the screw.

During the course of measurements of the scattering of γ-radiation in air, it has been found that the pocket integrating ion chamber type B.D.11 intended for personnel protection, employing an "air-wall" of a graphite-Bakelite mixture,* affords a convenient, reliable and accurate method of measuring γ-radiation dose when used in conjunction with the Baldwin–Farmer electrometer.

In order to obtain a true measure of scattered radiation arriving from several directions simultaneously, it was necessary to know the variation of the response of the chambers when oriented differently with respect to incident radiation coming from one direction only.

Fig. 1 shows the results of four separate calibrations of twenty-five standard B.D.11 chambers in four different orientations as shown in the inset. The chambers were supported on light Duralumin thin-walled tubes, 3 ft 6 in. long, erected vertically on the circumference of a circle of radius 1 m, at the centre of which was a similar tube supporting a source of 10 mg of radium. The screws of the chamber were left loose during the seven-hour exposure, and the correction applied for the average temperature and pressure of the room during this time. The usual correction for the sharing of charge with the electrometer input capacity was made.

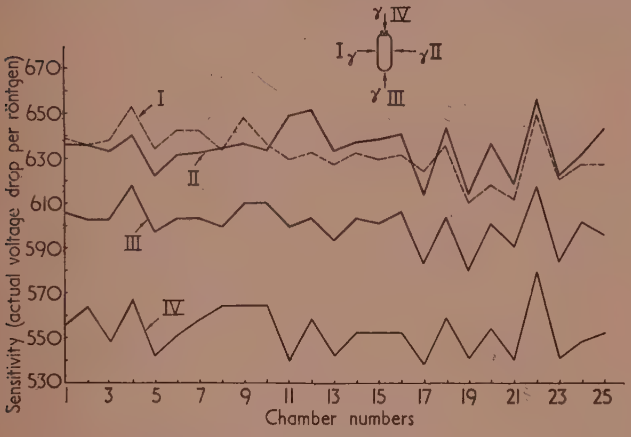


Fig. 1. Variation of sensitivity of standard B.D.11 chambers with orientation

Source, 10 mg radium; time of exposure, 7 h.

It is seen that, whereas the sensitivity of the chambers expressed as actual volts lost per röntgen is sensibly the same for radiation received in either of two opposite directions perpendicular to the axis of the chamber, for radiation received along the axis, either through the round or the screw end, the sensitivity is less by about 5 and 13% respectively.

It seemed reasonable to suppose that the more nearly spherical the form of the chambers, the more likely was the response to be uniform. Accordingly a number of chambers were constructed similar to the standard type B.D.11, but shorter. The overall length was reduced by shortening the longer component of the chamber with corresponding reduction in the length of the central electrode. Chambers were constructed with overall lengths of 39·5, 32·5, 26·5 and 21·5 mm compared with the overall length (including the screw) for the standard B.D.11 chamber of 46·5 mm.

The results showed that the 32·5 mm chambers and shorter chambers do not have an appreciably reduced sensitivity for radiation along the axis incident on the round end. Chambers shorter than 32·5 mm overall length, however, have less sensitivity and a smaller capacity. The latter means that the fall in voltage as measured on the electrometer must be multiplied by a larger correction factor and the resultant values are, therefore, of less accuracy.

It was therefore decided to adopt the 32·5 mm chamber for measurements upon radiation received from several directions simultaneously.

Fig. 2 shows the results of calibrations of twenty-one such modified B.D.11 chambers in three positions. Curve I represents the mean of three calibrations whereas curves II and III are the results of single calibrations. For curve I the radiation was incident at right angles to the chamber axis. Curve II is similar except that radiation was incident on the opposite side. Curve III shows the results for radiation incident on the rounded end of the chamber and shows that

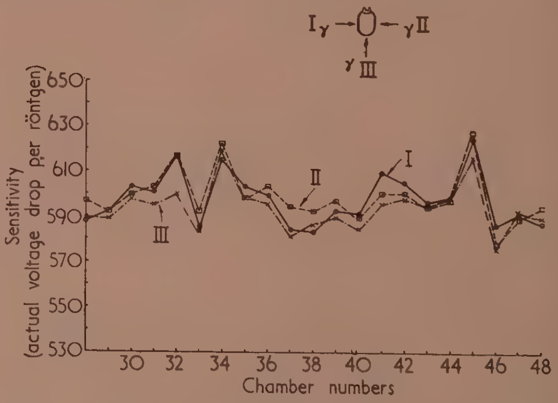


Fig. 2. Variation of sensitivity of 32·5 mm chambers with orientation

Source, 57 mc cobalt 60; time of exposure, 30 min.

---

* 17th Annual Report of the British Empire Cancer Campaign, p. 118 (1940).

he calibration figures for this position are essentially the ame as for the other positions.

These confirmatory experiments were made with a source f radio-cobalt emitting 1·25 MeV γ-radiation, whereas the reliminary investigations were made with radium sources with an effective energy of 0·84 MeV.

It is apparent that the polar uniformity of sensitivity of the 32·5 mm chambers is not appreciably affected by the quality of the radiation over this range.

ACKNOWLEDGEMENTS

Thanks are due to the Admiralty for permission to publish this paper and to the Baldwin Instrument Co. for the provision of the shortened chambers.

A thermocouple anemometer

By R. F. Benseman, B.Sc., and H. R. Hart, Dominion Physical Laboratory, Department of Scientific and Industrial Research, Lower Hutt, New Zealand

[*Paper first received* 13 *October, and in final form* 16 *November*, 1954]

A simple anemometer for measuring airspeeds from below 0·01 ft/s and up to any desired value is described. It can be used over a wide range of temperature and for remote indication with either a recorder or moving coil meter. In addition, the instrument can be adapted to measure airflows down to less than 0·0005 ft³/min. The instrument is reasonably robust, can be safely cleaned and its calibration should remain constant indefinitely.

This instrument was developed originally for recording airpeeds in blast-freezing chambers at meat works in New Zealand. Owing to inaccessibility and low temperature about —20° C) and because a continuous record of airpeed was required, the vane type of anemometer was unuitable. The use of other types of anemometers to give emote indication was considered. These included a modified orm of Thomas⁽¹⁾ meter similar to an instrument described by Moss.⁽²⁾ The Thomas meter is based on a principle described by Callendar⁽³⁾ and is used for measuring large mass flows and employs much associated equipment. Another nstrument is the Simmons shielded thermocouple anemometer.^(4,5,6) This instrument was not considered suitable for his particular purpose because of its restricted airspeed ange and because of the complex associated equipment needed to maintain accuracy if the instrument is to be operated for long periods without attention. Hot wire anemometers of the conventional type are obviously too ragile and are unstable over long periods due to dust particles collecting on the hot wire. A fuller description of the nstruments mentioned so far is given by Ower.⁽⁷⁾

The instrument about to be described (and referred to in he following notes as the "original model") was developed for multiple use with a strip-chart recorder. By taking care o make the instruments closely similar, eight units were made to have calibrations lying within 1% in the range 5 to 25 ft/s. They were tested by passing them horizontally hrough air initially at rest, on a whirling arm of 12 ft radius. With improved testing facilities⁽⁵⁾ it is found that the same nstrument can be successfully used in the range 0 to 2 ft/s and during tests consistent measurements of horizontal air drift as slow as 1 in./min have been made. The same principle is employed in another model made for laboratory use. Air is collected in one side of a twin-bore tube placed n the airstream. The air is passed *via* flexible tubing to the ensitive element (anemometer) and then back into the airtream. By using various sized jets to restrict the airflow the nstrument is made to indicate airspeeds over a number of anges, the most sensitive being from 1 ft/s downwards. It will also measure airflows to considerably less than 1 in.³/min. This model will be referred to as the "laboratory" model in he following notes.

DESIGN AND CONSTRUCTION

The original instrument consists of a short tube with a heating grid mounted half-way along its length and at right angles to its axis. On each side of the heating grid and equidistant from it are a number of thermocouples. These are placed across the centre-line of the tube and interconnected differentially. When air is in motion through the tube the thermocouples in front of the heated grid assume ambient air temperature, whilst those at the rear are heated by an amount dependent on the mass of air passing through the tube. The instrument is, in effect, a mass flowmeter so that temperature change occurring between the thermocouples depends on the volume and the specific heat of gas passing through the tube. As the specific heat of air (and most gases) is practically constant at normal pressures and temperatures, the instrument can be used to measure airspeeds in the range 0 to 100 ft/s say, with an accuracy of better than 1%. Up to a certain airspeed the output from the thermocouples increases with increase in airspeed, but beyond this "critical speed" the output falls logarithmically (Fig. 1). The instrument can be used in the range of airspeeds on either side of the critical speed but it is obviously more convenient to use

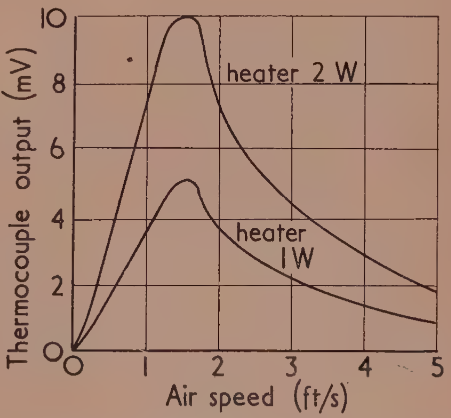


Fig. 1. Typical calibration curves of thermocouple anemometer

the first part of the curve. To eliminate ambiguity an instrument adjusted to have its critical speed above the range of measurements can be used. The critical speed is determined by:

(i) the distance of the thermocouples from the heating grid (especially the heated thermocouples);

> [In experiments to determine the best position of thermocouples relative to heater it was found that with bare thermocouples mounted horizontally and placed $\frac{1}{8}$ in. from the heating grid, the lowest figure obtained for the critical speed was about 0·25 ft/s.]

(ii) the ratio of airflow through the instrument to airflow through the same section in free air.

> [When the instrument is used as an anemometer the critical speed can be made to occur at any desired value above the minimum. This is done by restricting the airflow through the instrument (by means of glass tubes in the original model and by various sized jets used with the laboratory model). When the instrument is used as a flowmeter and all the air passes through it, this ratio is therefore unity. By passing some of the air through a jet in parallel with the instrument it can be used to measure any desired airflow.
>
> The shape of the calibration curve is the same whatever the range of airspeed or airflow. Therefore a common scale can be used on an indicating instrument for a number of ranges and it is only necessary to determine the constants for the jets.]

Radiation from sources outside the instrument does not affect its accuracy and radiation from the heating grid to the thermocouples is cancelled out by having the hot and cold junctions at the same distance from the heater. When used as an anemometer it is advantageous to enclose all wires within the instrument in fine glass tubes for the following reasons:

(i) instruments with similar calibration characteristics are more easily made, since the wires are supported in the same relative position;
(ii) the wires are protected from corrosion and the instrument may be cleaned without danger of changing its calibration;
(iii) the instrument is damped and the response time is increased—this may be an advantage in some cases in unsteady airstreams;
(iv) assembly is made much easier.

It is considered that construction could be made even more robust and assembly made easier by using fine metal tubes to enclose thin-walled glass insulators.

Because of symmetrical construction the original instrument can be used with either end facing into the airstream, but below airspeeds of 2 ft/s it is advisable to calibrate each unit in the direction which it is to be used.

The construction of the original model (Fig. 2) is as follows:

The thermocouple and heater assemblies are housed in a 1 in. square steel tube which is mounted on a hollow strut. The four leads to the instrument are fitted inside the strut. Junctions between the fine wires of the thermocouple and heater assemblies, and the four leads, are made by flattening the ends of the leads—by rolling them—and fitting them on to a mica strip. The fine wires are soldered on to the flattened ends of the leads. The heater and thermocouple wires are housed in soda glass tubes 0·040 in. outer diameter ×0·006 in. inner diameter. The distance from the cent
line of the thermocouple tubes to the centre-line of the heat
tubes is 0·125 in. There are two sets of ten glass tubes fo
the thermocouples and one set of ten for the heating wir
Tubes in each set are equispaced and located in holes drille
in the square tube and held in position temporarily wit
a high-temperature varnish. A multi-junction coppe
constantan thermocouple wire is threaded into the tubes s

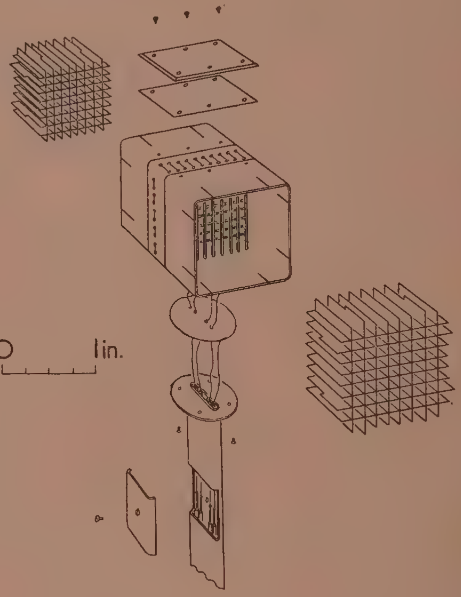


Fig. 2. Exploded view of original thermocouple anemometer

that all the copper-to-constantan junctions are on one side o
the heating grid, whilst all the constantan-to-copper junctions
are on the other. (Chromel–Alumel wires would be stronge
but the junctions are easier to see through the glass tubes
when copper and constantan wires are used.) Junctions are
in the eight centre tubes on each side of the heating grid, the
outermost tubes containing copper wires of the same diameter.
These form intermediate leads from the ends of the thermocouples to the heavier leads in the strut. The thermocouple
and heater wires are insulated from the square steel tube by
mica strips recessed in the outside of the tube. Both ends o
the square tube are fitted with guide vanes $\frac{1}{2}$ in. long. The
multi-junction thermocouple wire is made as follows:

The ends of the wires are cleaned with very fine abrasive
paper and cut off square with a clean, sharp pair of scissors.
The wires are dipped in a borax solution, clamped in a jig
so that their ends are in line and separated by not more than
quarter diameter. The ends are examined for alinement with
a low-power microscope and small adjustments made with a
scriber. Very fine particles of silver solder—produced by
filing—are mixed with a small amount of the borax solution
to make up a fairly thick paste. A speck of this paste is
transferred to the junction of the wires with the aid of a
scriber, and provided the flux on the wires is wet, the paste
is attracted to it by surface tension. By this means the wires
are not accidentally bent by the scriber touching them
Fusion of the solder is attained by quickly passing a fine gas
flame across the junction. The resulting join is inspected
under the microscope after the removal of flux and the
diameter of the junction is slightly greater than the wires

·005 in.) but small enough to pass through a hole of 006 in. diameter. Lengths of wire 1¼ in. long, alternately pper and constantan, are joined end to end in this manner make sixteen junctions in one continuous length of wire. 'he same technique has been used in joining wires of 001 in. diameter.)

The laboratory model mentioned earlier consists essentially a brass block with a square hole (0·342 in. across the flats) ross which the thermocouple and heater wires are mounted, e spacing between them being the same as in the original odel, i.e. 0·125 in. In order to increase the sensitivity and sponsiveness of the instrument the wires are bare but sulated within the brass block by short glass tubes. As air asses only through the block and not around the unit as efore, the instrument is easier to assemble. The complete strument is arranged to indicate airspeeds or airflows on a oving coil meter or can be connected to a recorder, in hich case the meter shows the heater current.

CALIBRATION

The original model heater resistance is approximately 26 Ω nd the thermocouple resistance 14 Ω. The heater current as maintained at 250 mA at all airspeeds. Sensitivity is irectly proportional to power input (changes in the resistance f the heater wire at various airspeeds have a negligible effect n the sensitivity). With a heater current of 250 mA the nput is about 1·6 W. It follows, therefore, that if the heater urrent changes by 1%, the change in thermocouple output ill be approximately 2%. The instrument has been operated ith heater currents up to 400 mA d.c. (4·16 W) but sufficient ensitivity is obtained with a current of 250 mA for the nstrument to be used satisfactorily with a recorder or meter aving a range of 0 to 10 mV. Calibrations at speeds between and 2 ft/s were made on an enclosed whirling arm of 10 in. adius. The apparatus and method of correcting for swirl ithin the enclosed space was similar to that used by owdrey.(5) The output when the instrument is stationary still air and when it is supported in its normal upright osition, should theoretically be zero. However, due to ight imperfections in manufacture this is not so. To use ne anemometer accurately for very low speeds it is necessary mount it in the attitude in which it was calibrated. The ttitude can easily be checked by covering the open ends of ne anemometer tube and noting the output. This should e the same as a reading taken with the ends covered and at zero speed when the instrument is set up on the whirling arm for calibration. By tilting the instrument backwards or forwards the zero reading can be made to exactly coincide with the zero of the calibration curve. The change in output due to pitch or roll of the instrument from its normal upright position is shown in Fig. 3. The effect of yaw using the instrument with and without guide vanes is shown in Fig. 4.

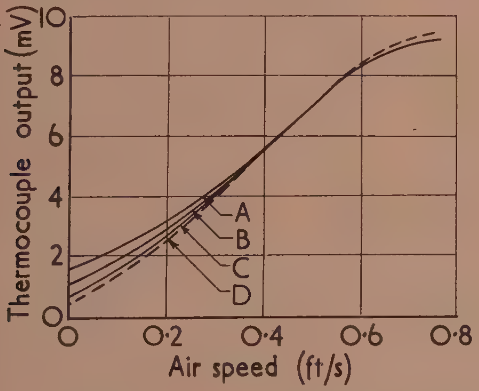


Fig. 3. Change of calibration of original instrument due to pitch or roll

A, anemometer tilted 10° forward; *B*, anemometer tilted 5° forward; *C*, strut vertical; *D*, strut horizontal.

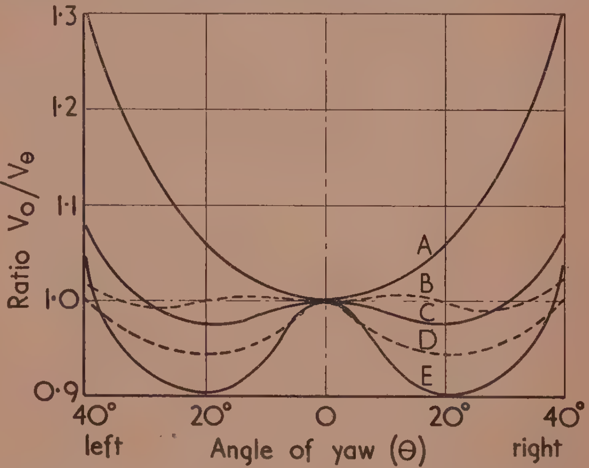


Fig. 4. Change of calibration of original instrument due to yaw

A, theoretical curve; *B*, without guide vanes, strut horizontal; *C*, with guide vanes, strut horizontal; *D*, without guide vanes, strut vertical; *E*, with guide vanes, strut vertical.

If the instrument gave a true indication of the component of airspeed parallel to its axis, then the ratio V_0/V_θ

(where V_0 = speed as shown by instrument when parallel to airstream
and V_θ = speed as shown by instrument when at angle θ to airstream)

plotted against angle of mis-alinement θ, would result in the curve *A* (Fig. 4). Similar errors occur with anemometers of the vane type.(8) The response time for the original instrument to take up 90% of a sudden change in airspeed from one level to another is about 10 s. Similarly, for the laboratory model (using bare wires) the response time is less than 1 s.

ACKNOWLEDGEMENTS

The work described in this paper was carried out at the Dominion Physical Laboratory and is submitted for publication by kind permission of the Secretary of the Department of Scientific and Industrial Research, New Zealand.

REFERENCES

(1) Thomas, C. C. *J. Franklin Inst.*, **172**, p. 411 (1911).
(2) Moss, H. *Proc. Instn Mech. Engrs*, **1**, p. 345 (1924).
(3) Callendar, H. L. *Phil. Trans A*, **199**, pp. 313, 314 (1902).
(4) Simmons, L. F. G. *J. Sci. Instrum.*, **26**, p. 407 (1949).
(5) Cowdrey, C. F. *J. Sci. Instrum.*, **27**, p. 327 (1950).
(6) Fox, L. L., Palmer, P. L., and Whittaker, D. *J. Sci. Instrum.*, **27**, p. 289 (1950).
(7) Ower, E. *The Measurement of Airflow*, 3rd Ed., p. 261 (London: Chapman and Hall Ltd., 1949).
(8) Heald, R. H., and Baliff, P. S. *J. Res. Nat. Bur. Stand.*, **19**, p. 685 (1937).

Laboratory and workshop notes

A magnetic pump for the laboratory

By J. S. George, B.Sc., Fats Research Laboratory, Department of Scientific and Industrial Research, Wellington, New Zealand

[*Note first received* 5 *July, and in final form* 14 *August*, 1954]

A magnetic pump is described which was used as a cycling unit on a laboratory molecular still. The pumping unit, Fig. 1, has general application in the laboratory and can be used for liquids of fairly high viscosity. Depending on the materials from which the pump is made, it can also be used for corrosive liquids.

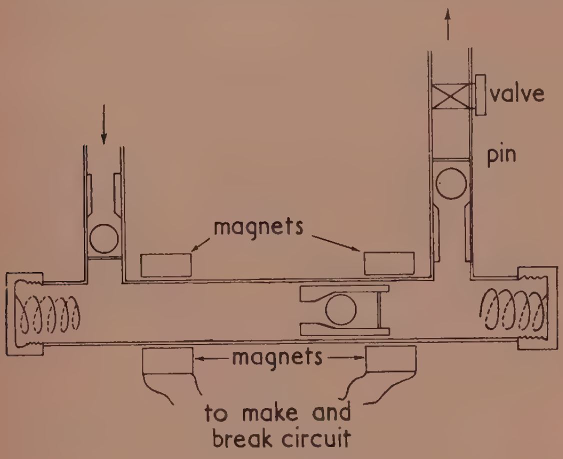


Fig. 1. Pumping unit

If an iron plunger would be attacked by the liquid being pumped it can be electroplated with an inert metal; the clearance between the plunger and walls of the pump body should be left at 0·003–0·005 in. all around. Alternatively, the non-return valve system of the plunger can be made from an inert plastic and inserted into an electroplated iron cylinder to form a composite plunger (Fig. 2). The non-return valve at each end of the pump can be made from an inert plastic or from inert metal, or made from steel and electroplated with inert metal.

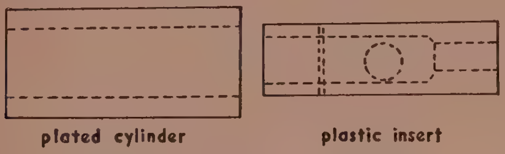


Fig. 2. Composite plunger

Using a make and break circuit and any suitable power supply, current is pulsed alternately through the magnet coils at a preset rate. The length of the stroke of the plunger can be varied as required by positioning the magnets. Coil springs are fitted to the screw caps on the ends of the pump to absorb the shock in case a breakdown occurs in the feed and the plunger overshoots the magnet. A valve is fitted to the outlet side of the pump.

By varying the rate at which power is supplied to the magnets, the distance between the magnets and the adjustment of the valve, the rate of flow can be varied from a gallon to a few centimetres per hour.

A simple chatter-proof electronic relay

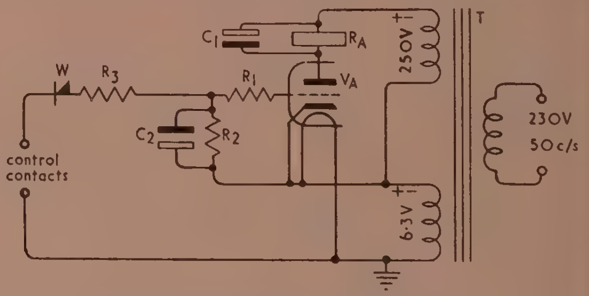
By L. A. Cram, B.Sc., The Imperial Tobacco Co. (of Great Britain and Ireland), Ltd., Bristol

[*Note first received* 28 *September, and in final form* 18 *October*, 1954]

Control of several kinds of physical change can be achieve by using the expansion which the change produces in suitabl materials and causing it to operate small electrical contacts If close control is needed sensitive contacts will be used These are frequently affected by vibration and cause chattering and arcing at the heavy current relay. This has bee overcome by incorporating a delay network in the electroni relay.

Circuits of the type shown in the figure have been use continuously for the past two years. The circuit is very simpl and experience has shown it to be reliable. It has been use in conjunction with bimetallic strips and toluene regulator for temperature control and with goldbeater's skin fo humidity control. In many of these cases vibrations from nearby motors have been unavoidable and the delay network has proved essential. Since only one-half of a double triode is used the other half can be wired into a similar circui (using the same mains transformer). A double relay is thu produced at little extra cost. This is ideal for two-step control, e.g. of liquid level. Also, it is often convenient fo the control of two separate variables, such as the humidity and temperature in a room or the temperatures of two wate baths.

Electronic relay circuits have been described by Pfestorf* and Rau† but they did not incorporate any delay. The present circuit uses a lighter current valve with smalle associated components and the heater is not under-run Furthermore, a standard double-wound transformer is used to avoid having the mains line (even neutral) connected to the control contacts. These contacts are sometimes handled for adjustments and, moreover, one of them may be earthed.



Circuit diagram of relay with delay

R_1 = 220 kΩ, ½ W
R_2 = 1 MΩ, ½ W
R_3 = 33 kΩ, ½ W
W = Westector type W3 (by The Westinghouse Brake and Signal Co., Ltd.)
C_1 = 4 μF
C_2 = 8 μF
R_A = P.O. 3000 relay, 10 kΩ
V_A = ½ 12AT7
T = 230/250 V, 20 mA, 6·3V, 1A, 50 c/s

The relay requires only about 2·5 mA half-wave a.c. t operate it. When the control contacts are open the hal 12AT7 V_A passes about 5·0 mA which holds the rela operated. When the control contacts close negative grid bia is applied and cuts off the valve almost immediately. Thi ias is produced by half-wave rectification of the heater oltage with a rectifier *W*. When the control contacts eopen C_2 must partially discharge through R_2 before pernitting sufficient anode current to close the relay. This ntroduces a delay of about eight seconds which has proved mple in all applications so far.

---

* Pfestorf, G. K. M. *J. Sci. Instrum.*, **29**, p. 378 (1952).
† Rau, R. S. N. *J. Sci. Instrum.*, **31**, p. 264 (1954).

Chattering may occur at either make or break. It consists f the rapid opening and closing of the contacts. To prevent he relay from following this chatter it is only necessary to elay its response to either the opening or the closing of the hattering contacts. In this circuit, delay at opening has been ncorporated. A slight delay (¼ s) at closing of contacts s indeed caused by R_3C_2 but this is incidental and the primary urpose of R_3 is to limit the current through the contacts at he instant of closing. At the instant of opening, the current hrough the contacts is limited by R_2, and is only 6 μA.

In cases where the contacts are not affected by vibration, he delay network and associated components (i.e. *W*, R_3 nd C_2) can be omitted and the circuit then reduces to the ormal one with out-of-phase voltage (derived from the eater winding of the transformer) as its grid control signal.

An adjustable strut for use in measuring instruments

By L. W. Nickols, B.Sc.(Eng.), M.I.Mech.E., National Physical Laboratory, Teddington, Middlesex

[*Note received* 20 *October*, 1954]

n the design of certain engineers' measuring instruments it s necessary to provide a fine adjustment between the measurng anvil and the indicating mechanism, for use in setting the atter to a zero reading when the anvil is in contact with the etting standard. A convenient way of doing this is to use a trut, the length of which is adjustable. This strut must be igid and must have a highly sensitive means of setting, and referably a relatively large range. A simple longitudinal crewed adjustment for the length of the strut is frequently sed, and this arrangement is perfectly satisfactory so long s the required accuracy of setting is not too high. However, hen a very high accuracy is required—of the order of a few undred-thousandths of an inch or better—then the above eans of adjustment is no longer suitable, and a design of trut developed at the N.P.L. and described below may be sed. This latter strut is simple and cheap to manufacture.

The principle of operation of this design is based on the ending of a simple cantilever [Fig. 1(*a*)] to the free end of hich is applied a force *W* which produces a deflexion *y* easured normal to the plane containing the neutral surface f the unloaded cantilever. Due to the curvature, of radius , produced in the loaded cantilever, the horizontal comonent of the length shortens by an amount *x*. For relatively mall angles of deflexion θ, *y* is considerably greater than *x*. his fact is made use of in the design illustrated in Fig. 2(*a*). he strut comprises two parallel steel strips *A*, which are onnected together rigidly at the ends by means of clamping lates *B* or other means. Each of the strips has a plate *C* ttached rigidly to it midway between its ends. By means f the adjusting screw *D* the two plates *C* may be pulled owards each other, thus reducing the overall length of the trut. In effect, the arrangement approximates to two sets f cantilevers, each set comprising four cantilevers placed nd to end, as shown in Fig. 2(*b*). If, by means of the central djusting screw, the two central plates are moved towards ach other from the unloaded position by a total amount $4y$, hen the overall length of the strut is reduced by $4x$. The ratio $4y/4x$ is therefore the same as the y/x ratio of a single simple cantilever. Values of this ratio y/x for angles of deflexion θ up to 15° are given in Fig. 1(*b*), and it will be seen that high magnifications are readily obtainable, particularly for the smaller angles of deflexion. In addition, if the adjusting screw *D* [Fig. 2(*a*)] has a fine pitch, then a very high accuracy of setting may be obtained.

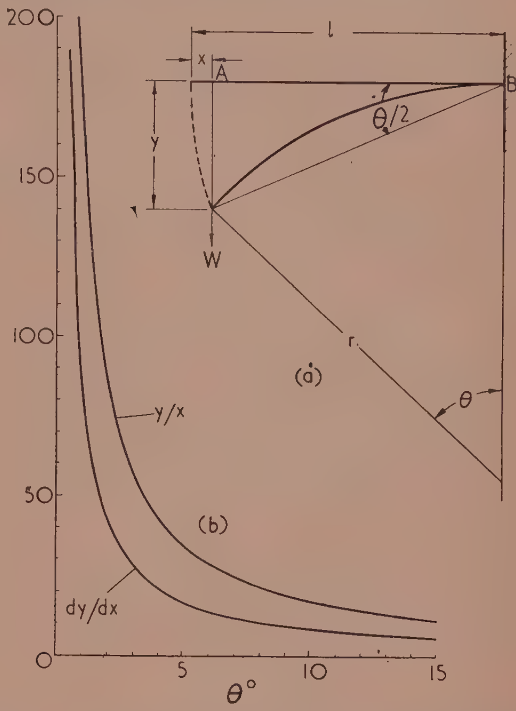


Fig. 1. (*a*) Bending of simple cantilever loaded at free end; (*b*) Design curves used in calculating theoretical dimensions of adjustable strut

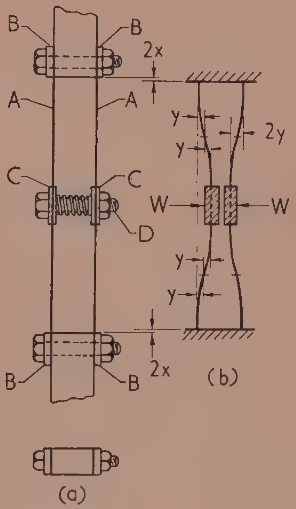


Fig. 2. (*a*) Construction of adjustable strut; (*b*) Diagram showing principles of operation of adjustable strut

The accuracy of setting of the strut over its working range may be obtained to a degree of approximation sufficient for normal requirements by the use of the simple cantilever beam deflexion theory, and the method of calculation is given below.

From Fig. 1(*a*) we have $x = r(\theta - \sin\theta)$ (1)

$$y = r(1 - \cos\theta) \quad (2)$$

The sensitiveness of setting when the free end of the cantilever has been deflected through θ depends upon the relative rates of change of y and x at that point, i.e. upon dy/dx. From equations (1) and (2) we have

$$dy/dx = (1 - \theta\sin\theta - \cos\theta)/(\theta\cos\theta - \sin\theta) \quad (3)$$

Values of dy/dx for angles of deflexion θ up to 15° are given in Fig. 1(*b*).

The use of the design curves in Fig. 1(*b*) for calculating the dimensions of a typical strut is most easily explained by reference to a typical example.

EXAMPLE

A strut is required, having a length adjustable to an accuracy of $\pm 0{\cdot}000\,02$ in. ($\pm 0{\cdot}5\ \mu$) or better, over a range of adjustment of $0{\cdot}005$ in. ($127\ \mu$). The working length of the adjusting screw, a 4 BA screw of approximately 40 turns per in. ($0{\cdot}66$ mm pitch) is capable of being set to $\pm 0{\cdot}0002$ in. ($\pm 5\ \mu$). The maximum tensile force in the adjusting screw should not exceed about 10 lb ($4{\cdot}5$ kg).

(*a*) *Calculation of length of strip.*

$$dy/dx = 0{\cdot}0002/0{\cdot}000\,02 = 10$$

From Fig. 1(*b*). If $dy/dx = 10$, then $\theta = 8°\,45'$, and $y/x = 19{\cdot}5$

From Fig. 1(*a*). $y = AB\tan\theta/2 = (l - x)\tan\theta/2$ (4)

Substituting in equation (4) for y ($=19{\cdot}5x$) and $\theta/2$ we have $l = 256x$

$x = \frac{1}{4} \times$ total range of length adjustment $= 0{\cdot}001\,25$ in. ($32\ \mu$)

Hence $l = (256 \times 0{\cdot}001\,25) = 0{\cdot}32$ in. ($8{\cdot}1$ mm)

The free length of each strip between the end clamp and the central plate is therefore $0{\cdot}64$ in. ($16{\cdot}2$ mm).

(*b*) *Calculation of section of strip.* Using the conventional notation we have, for a simple cantilever loaded at its free end

deflexion $y = Wl^3/3EI$, where $I = bd^3/12$ (5)

The force W on the end of each cantilever is one-half the force applied to plate C by the central adjusting screw

$W = 5$ lb $\qquad l = 0{\cdot}32$ in.

$y = 19{\cdot}5x = 19{\cdot}5 \times (0{\cdot}005/4) = 0{\cdot}0244$ in. ($0{\cdot}620$ mm)

It is assumed that $E = 30 \times 10^6$ lb/in.^{2} ($21{\cdot}1 \times 10^5$ kg/cm^2) and $b = \frac{1}{4}$ in. ($6{\cdot}35$ mm).

Then from equation (5) $d = 0{\cdot}0153$ in. ($0{\cdot}39$ mm) i.e. the standard thickness of strip required is $0{\cdot}015$ in. ($0{\cdot}4$ mm).

It should be noted that the strut designed in the above way has the required accuracy of length adjustment ($\pm 0{\cdot}000\,02$ in.) when the angle of deflexion θ is $8°\,45'$. At smaller angles of deflexion the accuracy of setting is correspondingly greater.

The work described above was carried out as part of the Research Programme of the National Physical Laboratory, and this paper is published by permission of the Director of the Laboratory.

An absorption coefficient calculator

By E. G. S. Paige, B.Sc., Physics Research Laboratory, University of Reading

[*Note first received* 11 *October, and in final form* 19 *November*, 1954]

The optical absorption coefficient μ is related to the transmission T by

$$T = T_0\exp(-\mu x)$$

where x is the thickness of the specimen and T_0 is the transmission of a specimen of the same refractive index, but o negligible absorption. This equation is valid when th incident beam is normal to the polished surfaces and whe multiple reflexions within the specimen can be neglecte conditions which are often encountered.

When measuring the absorption bands arising from defect in solids the changes of refractive indices are frequently sma so that the values of T_0 calculated from the indices of th non-absorbing crystal can be used to compute μ withou serious error. In cases where large numbers of transmissio measurements have to be converted to absorption coefficient much time is saved if a simply operated calculator can b devised. Such a calculator is described in this note.

The above equation may be written as

$$\mu = (2{\cdot}3/x)\log_{10}(T_0/T)$$

In Fig. 1, if x and $2{\cdot}3$ are made equal to the base and perpendicular height of a right-angled triangle OPQ, then th value of μ is given by the perpendicular height of a simila

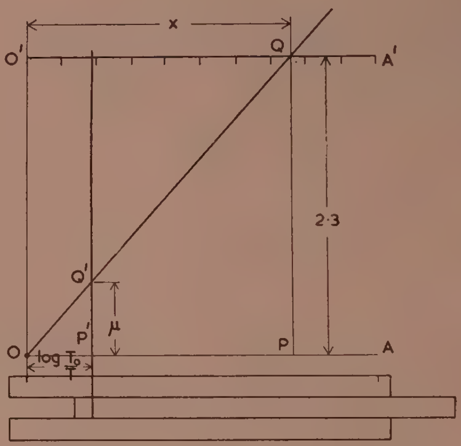


Fig. 1. Principle of the calculator

triangle $OP'Q'$ constructed on a base of length $\log_{10}(T_0/T$ A slide rule is used to calculate $\log_{10}(T_0/T)$, the result bein conveniently presented on a linear scale. Thus an ar $P'Q'$ attached to the slide of the slide rule, whose zero at O, is positioned automatically by dividing T_0 by T in th normal way.

The slide rule is held rigidly in a depression in a perspe base plate. A line OO' is engraved on the base perpendicula to the rule scales and intersecting them at their origi Pivoted at a point O on this line is a perspex arm, havin a reference line OQ engraved on its upper and lower face the line passes through the axis of rotation and runs th length of the arm. The arm may be moved over a linea scale $O'A'$ engraved on Ivorine and inlaid on the base plat

This scale, which must be identical to the scale of logarithms on the rule, is set perpendicular to the line OO' and has its origin exactly 23 cm from the point O.

On the lower face of the arm $P'Q'$ a line and millimetre scale are engraved perpendicular to and passing through the origin of the scale of numbers on the slide. When the slide is in an undisplaced position the line on the arm lies over the line OO' and the scale has its origin coincident with the point O. A photograph of the complete calculator is shown in Fig. 2.

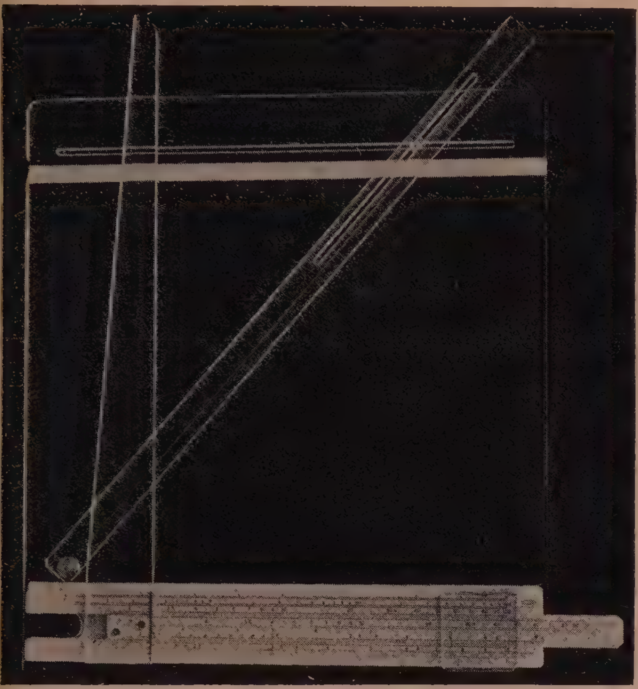


Fig. 2. Photograph of the calculator

Extreme care is necessary in positioning and engraving the scales. Errors due to parallax between scales and the lines indicating the readings on the scales have been avoided by their arrangement and by choosing the thickness of the arms so that they lie in contact.

To determine an absorption coefficient the sequence of operations is as follows: the arm OQ is positioned so that the reference line on it crosses the scale $O'A'$, the total length of which is equivalent to 1 cm, at the thickness of the specimen; T_0 is then divided by T on the slide rule and the value of the absorption coefficient is read off the scale $P'Q'$ where 1 dm ≡ 1 cm^{-1}. (This arises because 2·3 has been made 23 cm in the construction.) When a series of transmission measurements on the same specimen is being converted, the first operation need not be repeated. This feature makes the calculator particularly suitable for the evaluation of absorption spectra. For a specimen having $T = (50{\cdot}0 \pm 0{\cdot}2)\%$, $T_0 = (90{\cdot}0 \pm 0{\cdot}5)\%$ and $x = (0{\cdot}500 \pm 0{\cdot}0005)$ cm the value of the absorption coefficient can be calculated numerically to within $\pm 2{\cdot}0\%$. Using the calculator, the final estimated error in μ is not greater than $\pm 2{\cdot}5\%$. These errors vary with the values of T, T_0 and x, but in all cases the error introduced by the calculator is small compared with the experimental error.

Owing to the practical need to limit the length of the arms, they do not intersect for some combinations of x and T. This is simply rectified by setting the arm OQ at a thickness Ax where A is an integer; the values of the absorption coefficients read from the scale must be multiplied by A. Also, when T_0 is greater than $10T$ the characteristic of the logarithm (n) is no longer zero and a factor $(2{\cdot}3/x)n$ must be added to the calculated absorption coefficient.

The author wishes to thank Mr. Bull of the Instrument Workshop for constructing the calculator and to acknowledge a grant from the Department of Scientific and Industrial Research.

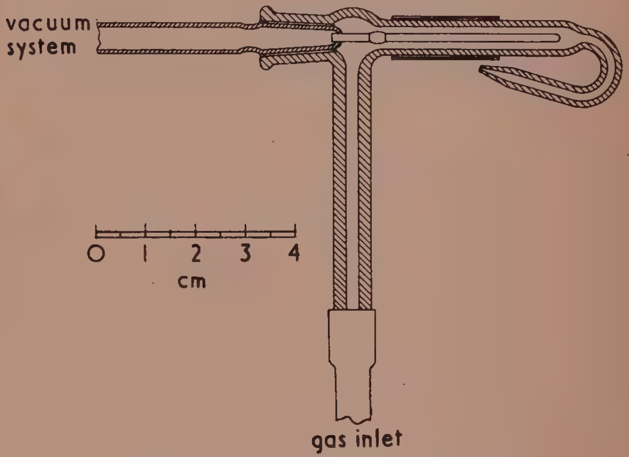
A convenient way of heating a palladium osmosis tube

By A. Leemans, Glassblowing Unit, c/o Department of Agriculture, University of Oxford

[*Paper received* 10 *December*, 1954]

Palladium osmosis tubes used for admitting pure hydrogen into a vacuum system are usually heated by a small electric heater. If the source of hydrogen is the town gas supply, a simple and effective means of heating is to utilize the escape jet.

The platinum extension of the standard type palladium osmosis tube is sealed in at the end of a ground lead-glass cone. A ground socket is made of borosilicate glass with enough space between the ground surfaces for one or two layers of 0·015 in. asbestos paper.



Palladium tube and heater assembled

The gas entry is a T-piece, also used for clamping the device to the vacuum system scaffolding. The socket tube is drawn out, ending in a fine jet capable of giving a flame of about 10 mm long. The drawn-out part is then bent back under the tube. Two turns of 0·2 mm nickel foil, wrapped round the tube where the flame touches, will prevent local overheating of the glass.

The two components are assembled by pressing them together with the wetted asbestos paper between the ground joint. Connexion to the vacuum system is made in the normal way.

The temperature inside the palladium tube was measured with a thermocouple. Readings of 400° C in the centre and 350° C at the closed end were obtained. Under these working conditions, the hydrogen penetrating the palladium tube raised the pressure in an evacuated 100 ml. reservoir to 200 mm of mercury in 90 s.

NOTES AND NEWS

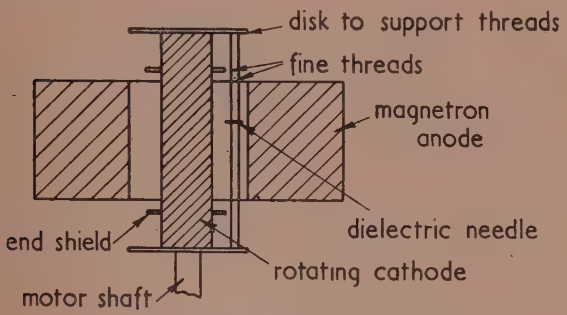
Correspondence

A proposed method of investigating the field distribution in a magnetron

It has long been established practice to use a rotating cathode probe(1) to display the field distribution within a multi-cavity magnetron anode excited by a low-power oscillator. This method is subject to several disadvantages. Firstly, it is difficult to obtain sufficient signal without the use of a long probe, and this introduces pattern distortion due to perturbation of the resonant frequency and cross-coupling between modes. Also the method measures only the radial field near to the cathode and there is some difficulty in extracting the signal from the rotating cathode.

The method suggested involves the use of a small perturbing object which would preferably take the form of a dielectric needle, the diameter of which is small compared with its length. The important property of such a needle is that it produces a perturbation of the resonant frequency of a cavity in which it is placed, which is proportional to the square of that component of electric field strength in the unperturbed cavity which is in the direction of the needle at the point where it is introduced.

The suggested experimental arrangement is as follows. A dummy cathode is fitted with two disks, one at each end, at distances from the anode such that they have no effect upon the anode cavity. Between these disks are stretched two thin fibres which support the ends of the dielectric needle, which would preferably be of small dimensions and high dielectric constant. This arrangement is shown in the figure. The cathode is rotated by means of an induction motor and a linear time base is triggered once per revolution by suitable contacts. For the most accurate display, a reflex klystron oscillator is locked in frequency to the anode cavity by means of a Pound stabilizer circuit,(2–4) the anode being excited through its output coupling loop or waveguide. In such a circuit the output of a phase-sensitive discriminator circuit is used to maintain the frequency of the oscillator at the resonant frequency of the stabilizing cavity by varying the reflector voltage of the klystron oscillator. Variations in the reflector voltage are proportional to changes in frequency and so the reflector voltage may be used for display on the triggered time base. The resulting display thus shows the variation in the square of the *E*-field component in the direction of the needle at the appropriate radius. A simpler method of display is to set the oscillator frequency at the point of steepest slope on either side of the resonance curve and to use the feed-through response as a measure of the change in frequency. By working on both sides of the curve it shoul be possible to assess the effect of nearby mode interference.



Rotating cathode with perturbing needle

The important feature of the method is that it permit the measurement at any radius within the anode-cathod space, and at any height, of the radial, azimuthal and axia variations of electric field round the anode bore inde pendently of one another, and makes a complete plot of th field in this space possible. Experience of perturbation method applied to other types of cavity makes it clear that the metho is entirely practical with existing techniques and it shoul prove a very useful tool for the magnetron designer.

The author wishes to thank Dr. Willis Jackson, Directo of Research and Education, and Mr. B. G. Churcher, Manage of the Research Department, Metropolitan-Vickers Electrica Co. Ltd., for permission to publish this note.

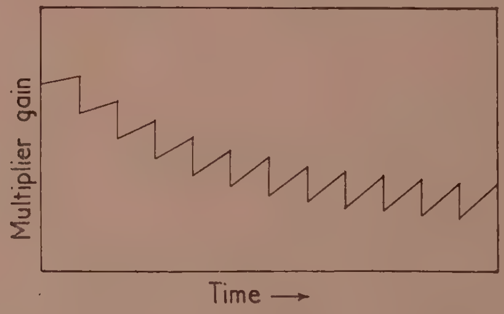
Metropolitan-Vickers Electrical Co. Ltd., A. W. Aikin
Trafford Park,
Manchester.

REFERENCES

(1) Willshaw, W. E., and others. *J. Instn Elect. Engrs*, **93** IIIA, p. 985 (1946).
(2) Pound, R. V. *Proc. Instn Radio Engrs*, **35**, p. 1405 (1947)
(3) Tuller, W. C., Galloway, W. C., and Zaffrano, F. P *Proc. Instn Radio Engrs*, **36**, p. 754 (1948).
(4) Essen, L. *Proc. Instn Elect. Engrs*, **100**, III, p. 19 (1953)

Fatigue of photomultipliers under pulsed operation

Engstrom has published some data on the fatigue of photo-multiplier tubes which were illuminated by a constant ligh source.* It has since often been assumed that it is only th average current that matters for fatigue, and that large peak currents may be obtained without fatigue. The following phenomenological considerations show that this may not b true.



Illustrating fatigue of photomultipliers

The fatigue observed by Engstrom levelled off after abou ½ h, but the multiplication took about 24 h to recover. W may provisionally express the multiplication during fatigu by a formula,

$$M = M_0\{1 - \alpha i[1 - \exp(-\lambda t)]\} \quad (1$$

where t is the time after onset of fatigue, and during recover by a formula

$$M = M_0[1 - \alpha i \exp(-\mu t)] \quad (2$$

---

* Engstrom, R. W. *J. Opt. Soc. Amer.*, **37**, pp. 6,420 (1947).

here t is the time after the beginning of the recovery $\simeq 10^{-3}\,\mathrm{s}^{-1}$ and $\mu \simeq 5 \times 10^{-5}\,\mathrm{s}^{-1}$.

The fatigue from a series of short pulses may then be lculated if we assume that the initial rate of fatigue is dependent of the multiplication. Then a steady state is on reached where the multiplication is

$$M = M_0(1 - \alpha\bar{i}\lambda/\mu) \qquad (3)$$

here $\bar{i}$ is the average current. This is illustrated in the gure.

The fatigue is greater than that given by the average current the factor $\lambda/\mu \simeq 20$.

The assumptions made are, at best, only qualitatively orrect. However, enough has been said to emphasize that ngstrom's data may not directly apply to fatigue under ulsed operation.

larendon Laboratory,
xford.

R. WILSON

Modifications to a sedimentation apparatus

he sedimentation apparatus (by Imperial Chemical Industries td.) described by Stairmand* has been used for the size nalysis of zircon dust (specific gravity 4·7) elutriated to be ss than 13 μ (Stokes's diameter) and used as test dust for clone separator design studies.

Some simple modifications have been made to the sedi-entation tube (Fig. 1) and the accuracy of the instrument as been improved down to a particle size of about 2 μ.

In initial tests it was noticed that a considerable amount of ust settled in tube *A* leading from the clear water reservoir. his sediment was not washed away by the clear water stream hen taking a sample and the recovery from the tube was % of the dust introduced.

To eliminate this error, the tube *A* leading to the clear ater reservoir was reduced to a 1·5 mm diameter capillary, and the settling zone *B* was reduced in volume from 3 to about 1·5 cm^3. The capillary was fused to the settling zone in such a way that when the sample was taken, clear water entered the tube *B* tangentially. This gently swirling flow washed the walls of the settling zone; but to ensure that all the sediment was washed out it was found necessary to take a sample into a 5 cm^3 test-tube 30 s before, and a further sample at the correct time. In this manner the dust recovery was over 99%. The results obtained were consistent and, taking the particle shape factor into account, were in close agreement with those obtained by microscope count. Results of tests made before and after the modifications are compared in the table and Fig. 2.

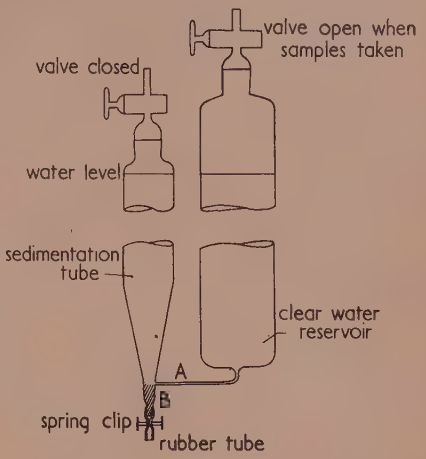


Fig. 1. Modified sedimentation tube and reservoir

Results of tests on sedimentation apparatus

Before modification

	Percentage weight in range					*Results/mean (%)*			
Range (μ)	*a*	*b*	*c*	*d*	*Mean*	*a*	*b*	*c*	*d*
0–2	15·5	19·0	9·5	15·0	14·75	105·0	128·5	64·4	102·1
2–4	21·5	20·0	19·5	25·0	21·5	100·0	94·0	90·7	115·3
4–6	15·0	21·5	22·0	17·0	18·9	79·5	114·0	116·5	90·0
6–8	17·5	19·0	16·0	14·5	16·75	104·2	113·2	95·4	87·2
8–10	18·0	11·5	17·5	11·0	14·5	124·0	79·4	120·5	75·8
10–12	9·5	7·45	10·0	13·0	9·99	95·1	74·7	100·1	130·1
12–14	2·55	1·45	4·44	4·1	3·13	81·4	46·3	142·0	130·3
14–16	0·45	0·1	0·06	0·4	0·25	180·0	40·0	24·0	156·0

After modification

	Percentage weight in range					*Results/mean (%)*			
Range (μ)	*e*	*f*	*g*	*h*	*Mean*	*e*	*f*	*g*	*h*
0–2	12·5	14·5	11·5	13·5	13·0	96·0	111·5	88·5	104·0
2–4	18·0	19·5	18·5	20·5	19·1	94·2	102·0	96·8	107·0
4–6	20·5	19·0	20·0	19·0	19·6	104·0	97·0	102·0	97·0
6–8	19·0	18·0	19·5	18·5	18·75	101·3	96·0	104·0	98·7
8–10	16·0	15·0	16·0	15·0	15·5	103·2	96·8	103·2	96·8
10–12	10·5	11·0	10·8	10·5	10·7	98·3	102·8	100·7	98·2
12–14	3·46	2·5	3·5	2·96	3·1	111·3	80·6	113·0	95·2
14–16	0·04	0·5	0·2	0·04	0·19	21·0	264·0	105·0	21·0

It was found possible to cover the size range 2–17 μ but at both ends of the range errors increased. The errors in determining the top sizes appear to result from the use of air bubbles to disperse the dust in the sedimentation tube immediately prior to the commencement of the test. In an attempt to avoid convection currents during the settling period, the stirring air was taken through a spiral tube immersed in a large water jacket surrounding the apparatus. However, the stirring operation caused currents in the sedimentation tube which persisted for varying periods up to 25 s after the bubbling had been stopped. Because the larger particles fall through the tube in 8–10 min, up to 5% of their falling period coincided with the decay of the stirring currents and errors in sizing result. As the size of the particles decreases, the falling period increases and the stirring currents have progressively less effect. Below 1·5 μ the settling time is long (about 24 h) and even small convection currents affect the accuracy.

---

* STAIRMAND, C. J. *Trans Inst. Chem. Eng. and Soc. Chem. Ind. mposium on Particle Size Analysis*, p. 128 (1947).

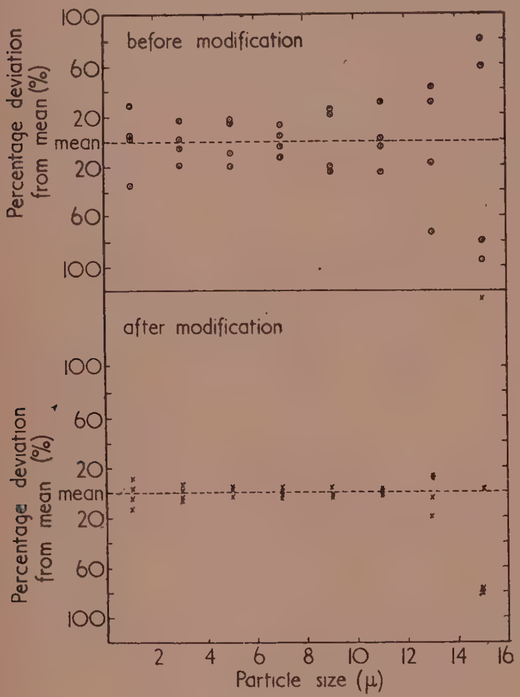


Fig. 2. Scatter of results

The work described in this letter was carried out under an arrangement with the Department of Scientific and Industrial Research for collaborative research on solid fuel firing for gas turbines.

J. Kobak

British Coal Utilisation Research Association,
Leatherhead, Surrey.

End-window radioactivity in photomultipliers

Audric and Long,(1) using two type 6260 photomultipliers (by Electric and Musical Industries Ltd.) viewing the same phosphor and operated in coincidence, have reported a background coincidence rate of 10 counts/min which they attributed to radioactivity of the photomultipliers. A spurious effect has also been reported by Parry.(2) In measurements designed to test the relative efficiencies of different photomultipliers with a NaI(Tl) crystal and a ^{60}Co γ-ray source, the photomultiplier gain was adjusted to give a background counting rate of 60 counts/min, with the phosphor in place; the counting rate was then determined with the source in a standard position. One type 5311 photomultiplier was found to give a higher counting rate than either of two type 6260 tubes of similar nominal overall sensitivity. Th type 5311 photomultiplier was made of glass having n potassium content and the type 6260 photomultipliers ha envelopes of soft boro-silicate (Kodial) glass which contain a small amount of potassium. It seemed likely that wherea the background from the type 5311 photomultiplier wa nearly all due to thermal emission, that of the other tube was due in part to ^{40}K radiation from the glass. Setting th initial counting rate at 60 counts/min therefore resulted in lower gain in the case of the type 6260 photomultipliers an hence a reduced sensitivity to the ^{60}Co radiation.

According to Sawyer and Wiedenbeck,(3) 1 g of natura potassium emits some 30 β-rays/s and 3·5 γ-rays/s. For photomultiplier window of weight 11 g containing 4% b weight of potassium monoxide, the total activity would b 650 β-rays/min and 75 γ-rays/min. Approximate calculation showed that, allowing for absorption in the glass, less tha 45 β-rays/min would be detectable on one side of the window The number of γ-rays detectable would also be considerabl reduced in most cases, probably by a factor of twenty or more

The calculations were checked by measuring the activit from a standard Kodial glass photomultiplier window placed directly on a 1 in. diameter and 1 in. high plasti phosphor, coupled with white Vaseline to a 14-stage photomultiplier. This tube had a Pyrex window; output pulse were phase-inverted and then fed directly into a scaler. Fo comparison, a plain Pyrex window and one covered with thin layer of 0·4 g of potassium chloride were also measure The results were as follows, the errors being the statistica standard deviations of the total counts:

No window	122 ± 1 counts/min
Kodial window	145 ± 2
Pyrex window	124 ± 2
KCl layer next to phosphor	156 ± 2
KCl plate reversed	121 ± 2
No window (repeat)	122 ± 3

The Kodial-window activity compared favourably with th expected value and with that of natural potassium. Pyre showed no activity and the thickness of glass used absorbe all the potassium activity, showing the γ-ray contribution t be negligible. Similar experiments with glass cylinder surrounding the phosphor gave comparable results, but bette agreement with the calculations which could be made rathe more accurately.

Measurements of the radioactivity of complete photo multipliers confirmed that the only significant contributio was from the window. A scintillation counter was agai used as detector, this time a small crystal of anthracen 15 × 13 × 4 mm, coupled to the same photomultiplier a before with microscope-immersion oil. The extra hig tension was set so that the thermal noise pulses were mostl below 5 V and the discriminator bias was at 10 V. An ide of the sensitivity can be obtained from the fact that a 10 μ source of ^{137}Cs, placed 6 in. from the crystal, and with $\frac{1}{16}$ in. aluminium sheet interposed, gave 900 counts/mi The multiplier being examined was placed with its windo facing that of the detector photomultiplier, about $\frac{1}{8}$ in. awa from the crystal, the whole being covered to exclude ligh The measurements gave:

Background	31 ± 1 counts/min
Kodial photomultiplier	40 ± 1
Pyrex photomultiplier	30 ± 1

The Kodial photomultiplier had an envelope wholly Kodial glass; the Pyrex tube had the window and top secti

Pyrex with a graded glass seal to the bottom section and se which was necessarily of Kodial.

The experiments have demonstrated that a small, though most cases negligible, background can arise from photo-ultipliers used as scintillation counters, when the window contact with the phosphor contains potassium. In view this, some photomultipliers are now being manufactured Electric and Musical Industries Ltd. with Pyrex windows hich give no such effect.

esearch Laboratories,
lectric and Musical Industries Ltd.,
ayes, Middlesex.

A. G. HESTER

REFERENCES

) AUDRIC, B. N., and LONG, J. V. P. *J. Sci. Instrum.*, **30**, p. 467 (1953).
) PARRY, R. Y. Private communication to J. D. MCGEE.
) SAWYER, G. A., and WIEDENBECK, M. L. *Phys. Rev.*, **79**, p. 490 (1950).

Maximum sensitivity in pneumatic gauging

Vith reference to the paper by Mr. N. Stolow on page 416 f the November 1954 issue of this *Journal*, it is considered orth pointing out that the condition for maximum sensitivity hen a null-point method is used in pneumatic gauging is btained when $H_{eff} = \frac{1}{2}H$. It is true that for a given value f his parameter Q_0 the sensitivity is a maximum when the alue of h is such that $H_{eff} = \frac{2}{3}H$. However, with a null-oint method of working, it is the gap h which is fixed at a hosen value, and then the maximum sensitivity is obtained hen Q_0 is selected to make $H_{eff} = \frac{1}{2}H$.

Referring to Fig. 4 of the paper, page 418, for any partiular value of h, say h_N, the curve which has the maximum lope is the one which passes through the point $[h = h_N,$ $_{eff} = \frac{1}{2}H]$. The curves which intersect the ordinate $h = h_N$ bove and below this point have less slope at the point of ntersection. This result may be deduced from Mr. Stolow's quation for the sensitivity on page 418:

: is
$$S = \frac{dH_{eff}}{dh} = -3\left[\frac{K_s}{Q_0}\right]^{\frac{1}{3}}\left[H_{eff}^2\left(1 - \frac{H_{eff}}{H}\right)\right]^{\frac{2}{3}} \qquad (1)$$

f we substitute in this equation the value

$$H_{eff} = \frac{Q_0}{K_s h^3 + (Q_0/H)} \qquad (2)$$

nd differentiate with respect to Q_0 (keeping h fixed) we btain

$$\frac{dS}{dQ_0} = \frac{-3K_s^{\frac{4}{3}}h^3\left[\left(K_s h^3 + \frac{Q_0}{H}\right)^2 - \frac{2Q_0}{H}\left(K_s h^3 + \frac{Q_0}{H}\right)\right]}{\left(K_s h^3 + \frac{Q_0}{H}\right)^4}$$

nd it can be seen that the maximum sensitivity (for a fixed h) given when

$$K_s h^3 - (Q_0/H) = 0$$

Ience, from equation (2),

$$H_{eff} = \tfrac{1}{2}H$$

It can be shown that this result holds for any form of gap beying the general equation

$Q/H_{eff} = Kh^n + C$, where K and C are constants.

In practice, of course, with the values of h usually chosen, there is only a slight change in sensitivity with an alteration of the working conditions from $H_{eff} = \frac{1}{2}H$ to $H_{eff} = \frac{2}{3}H$.

It is interesting to consider the value of the maximum sensitivity for a chosen null-point h_N with a gap obeying the equation

$$Q/H_{eff} = Kh^n$$

Substituting

$$H_{eff} = \tfrac{1}{2}H \text{ and } Q_0 = HKh_N^n$$

in the general form of equation (1) we obtain

$$\left(\frac{dH_{eff}}{dh}\right)_{h=h_N} = -\frac{n}{4}\frac{H}{h_N}$$

Thus we see that the maximum sensitivity of the system for a chosen null-point is inversely proportional to the value h_N selected for the gap, is directly proportional to the pressure H and is independent of the Schiller constant K_s.

Physics Research Laboratory,
Ilford Limited,
Brentwood, Essex.

N. R. WYNN

Mr. Wynn is correct in saying that the maximum sensitivity occurs at $H_{eff} = \frac{1}{2}H$ according to his application of the pneumatic gauging method. When h is first set to some suitable value and then Q_0 is altered, it is found that dH_{eff}/dh is a maximum ($d^2H_{eff}/dhdQ_0 = 0$) for $H_{eff} = \frac{1}{2}H$.

However, in the practical operation of the author's apparatus as a null-point instrument, when pneumatic gauging measurements are made, Q_0 is not a variable. For example, when it is desired to locate a polymer film surface at a fixed distance h, Q_0 is first set at a certain value, the value of h being at infinity; one of the family of curves of Fig. 4 of the paper then comes into operation and the value of h is adjusted such that $H_{eff} = \frac{2}{3}H$, since this is the region of maximum sensitivity for each curve where $d^2H_{eff}/dh^2 = 0$. For each value of the parameter Q_0, the null-point h chosen, h_N, will be slightly different.

In practice, the choice of Q_0 is limited in the lower limit by the speed of response of the apparatus as discussed on page 418, and the upper limit is governed by the fact that equation (6) of the paper will not hold for high rates of flow; turbulence then sets in between the plates. It so happens that the choice of $\frac{2}{3}H$ or $\frac{1}{2}H$ for H_{eff} does not have much effect upon the sensitivity.

If $H_{eff} = \frac{2}{3}H$ for maximum sensitivity, then for a fixed h, e.g., h_N,

$$Q_0 = 2K_s H h_N^3$$

and if in the sensitivity expression

$$S = \frac{dH_{eff}}{dh} = -3\left[\frac{K_s}{Q_0}\right]^{\frac{1}{3}}\left[H_{eff}^2\left(1 - \frac{H_{eff}}{H}\right)\right]^{\frac{2}{3}}$$

the values of K_s/Q_0 and H_{eff} are substituted one obtains

$$S = -\tfrac{2}{3}\frac{H}{h_N}$$

which shows that the sensitivity is independent of the constant K_s as in Mr. Wynn's case, but that the coefficient is 2/3 instead of 3/4.

Department of Technology,
Courtauld Institute of Art,
University of London.

N. STOLOW

Notes and comments

Elections to The Institute of Physics

The following elections have been made by the Board of The Institute of Physics:

Fellows: W. H. Dowland, J. V. Dunworth, J. R. Greening, F. Hirst, A. G. Peace, J. Walker.

Associates: A. W. Badcock, P. S. Baker, J. A. W. Huggill, D. S. Barmby, J. V. Bromiley, I. D. Brotherton, J. C. Cockram, A. R. Crathorn, M. F. Culpin, D. S. Dodd, I. Flinn, R. A. Granville, A. C. Ham, A. R. James, D. B. G. James, B. R. Malcolm, R. W. Pickard, W. P. F. Raffan, D. A. E. Roberts, P. M. Rolph, R. P. Rose, K. W. Scott, M. J. Sheehy, A. Turner, E. R. Wooding, N. R. Wynn.

Thirty-seven Graduates, fifty-eight Students and five Subscribers were also elected.

Conference on the production and utilization of electromagnetically enriched isotopes

A conference on the production and utilization of electromagnetically enriched isotopes will be held at the Atomic Energy Research Establishment, Harwell, from 13 to 16 September inclusive. Sessions on the following subjects will be included: design and operation of large mass separators; ion source and collector problems, especially with high beam current; separation of radioactive materials; chemical aspects of production work; preparation of isotopic targets; developments on mass analysis of stable isotopes; utilization of electromagnetically enriched isotopes.

Although much of the available time will be occupied with problems of the electromagnetic separator itself, contributions will also be welcomed on applications of stable isotopes, especially those of an unusual type. The emphasis here should be on the principles involved and not on the details of the great variety of techniques which users may employ. On the other hand the great volume of work on the application of the isotopes of the lighter elements, particularly of hydrogen, carbon, nitrogen and oxygen which are more economically enriched by other methods, is specifically excluded.

The conference should provide an opportunity for bringing together people concerned with the production and use of stable isotopes and should stimulate further applications. Those wishing to attend should write immediately to Dr. M. L. Smith, Atomic Energy Research Establishment, Harwell, Didcot, Berks., indicating also whether they will make a written contribution. Abstracts of papers must be submitted before 30 April, and complete manuscripts before 30 June, 1955, so that reprints of the papers can be made available before the conference. Fuller details of the arrangements will be sent to those who respond to this preliminary notice.

British Instrument Industries' Exhibition

The third British Instrument Industries' Exhibition wi be held at Earls Court, London, from 28 June to 9 July, 1955 and advance notices of some of the more important exhibit will be published in the June issue of this *Journal*.

The exhibits will include the latest products of manufacturers of a wide range of scientific and electrical instruments including medical instruments, navigational equipmen industrial photographic equipment, industrial meters, automatic controls, scientific glassware, drawing office equipment, etc. Experienced technicians will be available t demonstrate the exhibits and various applications.

Further information may be obtained from the organizers F. W. Bridges and Sons, Ltd., Grand Buildings, Trafalga Square, London, W.C.2.

Joint conference on combustion

The Institution of Mechanical Engineers announces that i has arranged a joint conference on combustion with th American Society of Mechanical Engineers which will be held in Boston, Massachusetts from 15 to 17 June next and i London from 25 to 27 October next. Bearing in mind the inherent difficulty in applying theory to practice in the spher of combustion, the objects of the conference will be:

(i) to link theory and practice in this sphere by presenting the results of theoretical work to practical engineers i America, Great Britain and other countries; and

(ii) to provide an opportunity for practical engineers i these countries to meet together to discuss practica application of theory in the fields of boilers, furnaces internal combustion engines and gas turbines.

Some thirty other institutions and societies, including The Institute of Physics, are supporting the conference and thei members may obtain particulars and preliminary reply forms through these bodies. Others should apply to the Secretary of The Institution of Mechanical Engineers, 1 Birdcage Walk London, S.W.1.

British Journal of Applied Physics

Contents of the April issue

ORIGINAL CONTRIBUTIONS

The electrical conductivity and permittivity of mixtures, with special reference t emulsions of water in fuel oil. By C. A. R. Pearce.
Effect of low temperature on the stability of permanent magnets. By A. G. Clegg
The cracking of layers of brittle material by differential strains. By D. J. Millard
High-frequency plasma-electron oscillations. By K. G. Emeleus and R. A. Bailey
The solution of transient heat flow and heat transfer problems by relaxation By G. Liebmann.
Measurement of mass transfer by an electrical conductivity method. By E. W Gaylord and W. Forstall.
Low-frequency dynamic response of photo-sensitive neon discharge tubes. By T. J. Dillon.

NOTES AND NEWS

Correspondence

A rubber-membrane model for axially-symmetric electric fields. From B. J. Mayo
New books
Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principles, construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Square, London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation of contributions*. (Price 2*s*. 6*d*. including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon application from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, London, E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within 60 days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of address or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £4 per volume ($11.50 U.S.A.), including index (post paid) payable in advance. Single parts, so far as available, may be purchased at 8*s*. each ($1.15 U.S.A.), post paid, cash with order. Orders should be sent to The Institute of Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

History of electrical devices for measuring strains and small movements

By B. E. Noltingk, Ph.D., F. Inst.P., National Coal Board, Central Research Establishment II, Isleworth, Middlesex

The development of apparatus for measuring strains and small movements by transduction into electrical signals is traced over the past hundred years. Instruments depending on resistive, capacitive, inductive, piezoelectric, acoustic and photoelectric systems are considered, and the chief contributors to the introduction of different techniques are enumerated.

'he bonded electrical resistance strain gauge has had a very 'ide field of application over the last ten or twelve years and he term "strain gauge" has, in fact, tended to be identified 'ith such a device. It is, however, only one of a number of lectrical instruments used for the measurement of small dislacements. Since simple kinematic systems can be used to onvert other mechanical parameters—acceleration, pressure, tc.—into small movements, the subject of electrical equipient to measure these last-named covers a large part of the eld of electrical instrumentation for mechanical engineering.

Several books have been published covering the general ubject matter,(1–4) but it is of interest to survey briefly the istory of these developments and to try to assign credit for he origination of novel techniques. Most scientific practices we a great deal to the small improvements that have been ontributed by many different workers, and electric strain auging is no exception; however, it is generally possible to raw a fairly sharp line between basic novelty and mere nprovement of detail, and in this account we shall conentrate on the former.

As perhaps in most branches of instrumentation, the evelopment of electrical strain gauges and the like has been overned both by the demand for them and by the parallel evelopment of auxiliary apparatus, notably radio valve quipment. At first only occasional instruments were prouced intermittently, but since about 1918 the tempo has sen progressively, and apparatus has been made not only or a particular application where it was needed, but also in more general form so as to be available for attacking any roblem which might subsequently arise.

HISTORY OF DIFFERENT TYPES OF GAUGE

It is very nearly a hundred years since Lord Kelvin(5) (then ir William Thomson) first noted the change in resistance of wire under stress. This was confirmed by Wartmann(6) ho had been concerned about possible effects in the proposed ansatlantic submarine cable. The effect does not seem to ave been used for forty years until Lissell(7) and Bridgman(8) easured high pressures by means of the resistance changes ey produced.

Using a different technique, Guillet(9) in 1908 developed an strument in which large inductance changes were brought bout by small movements of an iron core. This had, in fect, a "push-pull" construction and quite closely resembled uch more recent devices. It could detect movements of 0^{-6} cm.

Three years later, mention is made of Johnson's marine rque-meter,(10) which had then been in successful use for ore than a year; its operation depended on the simple movement of the point of contact of a slider on a resistance wire, so that it was not particularly sensitive for very small displacements. Ytterberg's instrument(11) of 1912 was, strictly speaking, an electrical device for measuring a mechanical quantity, namely, angular acceleration. But, since it depended on manipulating the output from a generator in such a way as to give this result, it did not include a pick-up in quite the usual sense of the word and is not strictly comparable to other instruments described.

In 1915, Galitzine(12) gave the first account of an instrument based on piezoelectricity. The phenomenon had been discovered more than forty years previously by J. and P. Curie,(13) but had had no practical applications until Galitzine's accelerometer was produced. In that instrument, either a quartz or a tourmaline crystal could be used, and a string electrometer measured the charges generated when a suspended mass was pressed against the crystal by inertia forces.

At about that time, electronic devices generally, such as thermionic valves, underwent considerable development, and this is reflected in the progress of electrical strain gauges. It is particularly appropriate that J. J. Thomson(14) should be credited with the first recorded application of the cathode-ray tube to delineating the time variations of rapidly changing mechanical effects. At a demonstration on 11 April, 1919, he showed how tourmaline crystals could give an indication of explosion pressures on the screen of a primitive cathode-ray oscillograph, to the deflector plates of which they were directly connected. A (non-linear) time-base was provided by an alternating current passed through coils for magnetic deflexion of the spot.

The "acoustic strain gauge" converts small movements to changes in the natural frequency of a taut wire; the frequency can subsequently be measured electrically. This type of instrument originated, also in 1919, with Schyefe,(15) and has now been commercially available for twenty years.(16)

Resistive, inductive and piezoelectric pick-ups were thus the first types invented, to be followed by the acoustic unit. A capacitative pick-up needs rather more than the others in the way of auxiliary apparatus, and its appearance awaited the advent of a satisfactory thermionic valve. In 1920, Whiddington(17) produced his "ultra-micrometer," the first time that a capacity variation was used as a measure of a mechanical quantity. His circuit was based on the up-to-date principle of heterodyning two oscillators, one of them being frequency-modulated by the pick-up, with which a movement of 10^{-8} cm could just be detected. He was followed by Dowling,(18) whose apparatus differed from Whiddington's with regard to its circuit, but not in the basic principle that mechanical quantities brought about capacity variations.

Thomas in 1923$^{(19)}$ described a device in which the proximity of a metal plate to the coil of a valve oscillator altered the anode current of the latter. He pointed out that the high-frequency response of this equipment could be utilized by having an Einthoven string galvanometer as the final indicating instrument.

Torquemeters were a popular field of application at this time, Keinath$^{(20)}$ (1920) and Moullin$^{(21)}$ (1924) (his instrument was made by the Cambridge Instrument Co.) following Johnson's earlier model. Both the later instruments used the inductive principle, which was applied after that to an increasing amount of apparatus. The use of piezoelectric pick-ups also became quite widespread; Kluge and Linckh$^{(22)}$ in 1931 mention extensometers based on piezoelectricity, and Bloch$^{(23)}$ (1935) cemented crystals direct on the member, the strain of which was to be measured.

While the change in resistance of a wire was the first mechano-electric effect to be noted, practical resistive elements sensitive to longitudinal strains were one of the last types to appear. Peters and Johnston's$^{(24)}$ carbon pile "Telemeter" (1923) served as a strain gauge by indicating the variation in resistance as a stack of carbon disks were pressed together. A good deal of work was done with this sort of instrument to reduce its errors of hysteresis and non-linearity, but it was never so accurate as pick-ups in which metallic wire was used as the sensitive element. Nernst is credited with originating this idea,$^{(25, 26)}$ though Mayer's accelerometer$^{(27)}$ (1928) appears to be the first published account of the measurement of forces by their effect on the resistance of a stretched wire. Carlson's instrument$^{(28)}$ (1931) used the same principle in a strain gauge.

With all these gauges, the resistive unit was only fixed at its ends. A development also first mentioned by Bloch$^{(23)}$ was a carbon element that could be cemented directly on to the part to be examined. This idea soon became very popular, and led up to the bonded wire resistance strain gauge. In 1938, Clark and Datwyler$^{(29)}$ cemented wire on a stressed member in order to investigate stress-strain relations, and from this Simmons and Ruge$^{(30)}$ developed in the next few years the unit that has since been employed on such a large scale. Aughtie$^{(31)}$ and Jackson$^{(32)}$ originated different types of bonded resistance gauge.

Optical-electrical gauging devices were of necessity dependent on the development of photocells. Hence the first description of this type of instrument is as late as 1931, when Bergmann$^{(33)}$ discusses the use of a selenium barrier-layer photocell to detect angular movements. Two years later Labarthe$^{(34)}$ gave an account of an engine indicator in which the curvature of the reflecting back surface of a diaphragm altered with pressure, thus altering the intensity of a light-beam falling on a photocell.

CONCLUSION

In any history such as this, it is difficult to be certain that no omissions have been made; internal reports of new techniques may have had a limited circulation, while even patents or published articles may be overlooked in a survey that should extend across a century! Some purpose has been achieved if priorities have been suggested, even as a basis for future modification.

REFERENCES

(1) *The Measurement of Stress and Strain in Solids* (London: The Institute of Physics, 1948).

(2) PFLIER, P. M. *Elecktrischer Messung Mechanische Grössen.* 3rd ed. (Berlin: Springer-Verlag, 1948).

(3) HETENYI, M. *Handbook of Experimental Stress Analys* (New York: John Wiley and Sons, Inc., 1950).

(4) ROBERTS, H. C. *Mechanical Measurements by Electric Methods.* 2nd ed. (Pittsburgh: Instruments Publishin Co. Inc., 1951).

(5) THOMSON, W. *Phil. Trans*, **146**, p. 649 (1856).

(6) WARTMANN, E. *Phil. Mag.*, Ser. 4, **17**, p. 441 (1859).

(7) LISSELL, E. *Uppsala Univ. Årsskr. Mat. Naturv.*, No. (1903).

(8) BRIDGMAN, P. W. *Proc. Amer. Acad. Arts Sci.*, **47** p. 321 (1911).

(9) GUILLET, A. *C.R. Acad. Sci.* [*Paris*], **146**, p. 465 (1908)

(10) *Engineering*, **92**, p. 605 (1911).

(11) YTTERBERG, A. *Elektrotech. Z.* [*ETZ*], **23**, p. 115 (1912).

(12) GALITZINE, M. B. *C.R. Acad. Sci.* [*Paris*], **161**, pp. 281 304 (1915).

(13) CURIE, J., and CURIE, P. *C.R. Acad. Sci.* [*Paris*], **91** pp. 294, 383 (1880).

(14) THOMSON, J. J. *Engineering* [*London*], **107**, p. 543 (1919)

(15) SCHYEFE, O. *Z. Ver. Dtsch. Ing.* [*VDI*], **63**, p. 100 (1919).

(16) *Engineer*, **158**, p. 142 (1934).

(17) WHIDDINGTON, R. *Phil. Mag.*, **40**, p. 634 (1920).

(18) DOWLING, J. J. *Proc. Roy. Soc. Dublin*, **16**, p. 18 (1921)

(19) THOMAS, H. A. *Engineer*, **135**, p. 138 (1923).

(20) KEINATH, G. *Dinglers J.*, **335**, p. 265 (1920).

(21) *Engineering* [*London*], **117**, p. 764 (1924).

(22) KLUGE, J., and LINCKH, H. E. *Forsch. Ing. Wes.*, **2** p. 153 (1931).

(23) BLOCH, A. *Nature* [*London*], **136**, p. 223 (1935).

(24) PETERS, O. S., and JOHNSTON, R. S. *Proc. Amer. Soc Test Mater.*, **23**, p. 592 (1923).

(25) KEINATH, G. *Die Technik elektrischer Messgeräte* Vol. II, p. 329 (Munich: Oldenbourg–Verlag, 1928).

(26) CZERLINSKY, E. *Jb. Dtsch. VersAnst. Luftf.*, **2**, p. 37 (1938).

(27) MAYER, F. H. *Messtechnik*, **4**, p. 115 (1928).

(28) CARLSON, R. W. *Engng News Rec.*, **114**, p. 696 (1935)

(29) CLARK, D. S., and DATWYLER, G. *Proc. Amer. Soc Test Mater.*, **38**, p. 98 (1938).

(30) DE FOREST, A. V. *Instruments*, **15**, p. 112 (1942).

(31) AUGHTIE, F., and others. British Patent No. 560,26 (1942).

(32) JACKSON, P. G. *Instrum. Pract.*, **7**, p. 775 (1953).

(33) BERGMANN, L. *Phys. Z.*, **32**, p. 688 (1931).

(34) LABARTHE, A. *J. Soc. Ing. Auto.*, **6**, p. 2352 (1933).

The use of the milling machine for preparing bone sections for microradiography and microautoradiography

By JENIFER JOWSEY, B.A., Nuffield Department of Medicine, Oxford

[*Paper first received* 28 *January, and in final form* 23 *February*, 1955]

Undecalcified bone can be embedded in Perspex in an oven which is designed to hasten the polymerization of the Perspex monomer so that short-lived isotopes may be studied. The sections are cut on an engineer's milling machine to 100 μ and ground to approximately 50 μ on ground glass. The sections are then X-rayed and autoradiographed so that the degree of calcification and the uptake of different isotopes may be correlated, the autoradiographic film being left on the sections so that the exact localization of the isotope may be determined. Both large-grained X-ray film and fine-grained autoradiographic film are used, depending on the concentration of isotope in the bone. This method can be used for hard adult cortical bone with satisfactory results.

Studies on the structure of bones have in the past usually been carried out on decalcified tissue. The removal of the bone salts, while making it possible to cut the bones on a microtome, does not appreciably alter the cellular pattern. If, however, the deposition of mineral elements in the bone are of interest, it is essential to be able to cut thin undecalcified sections. Axelrod(1) has described a method applicable to rachitic or immature rat bones which, however, did not enable sections of undecalcified cortical bone from healthy adult animals to be prepared. More recently, Arnold and Jee(2) have described a method using a milling machine for cutting longitudinal sections of calcified adult bone which the authors themselves state is unsatisfactory when applied to cross-sections. In order to study in detail the site of deposition of radioactive elements in adult cortical bone, the method used for preparing macroscopic sections (500–700 μ)(3) has been modified and is now described. This method involves embedding bones in methyl methacrylate monomer which, after polymerization, is almost as hard as bone. Thin sections of bone thus embedded are cut with a fine circular saw, ground and left in contact with the autoradiographic film, so that the exact localization of the radioactive isotopes can be determined in relation to the histology and calcification of the bone. The resulting sections, which are 30–50 μ thick, can be cut in series at 500 μ apart throughout the length of a bone.(4) The same sections may be used to prepare microradiographs that show details of the degree of calcification of the bone in relation to the uptake of radioactive isotopes.(5)

PREPARATION OF THE MONOMER

The embedding medium is methyl methacrylate monomer (Kallodoc by Imperial Chemical Industries Ltd.). This contains an inhibitor, hydroquinone, which is removed by washing with a 5% solution of sodium hydroxide in a separatng funnel, the monomer forming the upper layer and the sodium hydroxide and inhibitor coming down to the bottom as a reddish-brown liquid. The process is repeated until there is no longer any coloration of the sodium hydroxide olution; the monomer is then washed free of excess alkali with distilled water. The monomer is run off into a beaker and dried overnight over calcium chloride in a desiccator. Benzoyl peroxide, which has been purified by standing over calcium carbonate until the pH is neutral, is then added to the monomer to hasten polymerization (0·5 g to 100 cm^3 of monomer). The activated monomer is filtered and stored in a refrigerator, as it tends to polymerize slowly at room temperatures. The polymerization of the monomer normally takes about 10 days or more, and to reduce the time taken to embed the bones after impregnation the catalyzed monomer is partly polymerized before use by heating it in a flask in boiling water. The temperature of the monomer should not rise above 80° C, since above that temperature a chain reaction starts which is exothermic and results in the monomer bubbling and expanding and finally setting hard all within a few seconds. The monomer is heated till it is approximately as thick as treacle, when it is returned to the refrigerator.

EMBEDDING

The bones to be cut are dissected from the animals, scraped clean of flesh and cut up with a fret-saw in a fume cupboard to avoid inhaling any radioactive bone dust. The bones are divided into convenient pieces; in the case of long bones the whole bone is cut in half transversely and the proximal half cut into three pieces, the head of the bone being cut off above the epiphyseal plate to facilitate embedding. The marrow is washed out with a jet of water, and the proximal ends of the three pieces of bone marked with a spot of red paint. The bits of bone are left in absolute alcohol for two or three days to fix and dehydrate; the alcohol is changed at least twice. In order to impregnate the bones they are then put in unpolymerized methyl methacrylate monomer in a vacuum desiccator and the pressure reduced two or three times to approximately 55 cm of mercury for a few seconds. Trapped air bubbles are thus pumped out and maximum penetration of the monomer into the bone tissues is ensured. They remain in this monomer for about 24 hours. They are then placed on small blocks of Perspex in glass boxes and covered with the partly polymerized liquid.

The boxes, which are made from glass slides stuck together with Durofix cement, are next put into a vacuum desiccator, evacuated again and left for 10 min, as air bubbles come out only slowly through the more viscous medium; any trapped air also escapes from the bone. The boxes are then covered with glass slides to prevent excessive evaporation and placed in an oven to complete the polymerization of the monomer.

THE OVEN

Unfortunately, the polymerization is a slow process and, if the monomer is overheated in an attempt to speed it up, it forms bubbles and expands so that the bone is not satisfactorily embedded. It must either be heated slowly and kept at 37° C, in which case hardening takes 7 to 10 days, or heated to 42° C and cooled down to room temperature every hour, which is a more rapid way of polymerizing the monomer. Since speed is an all-important factor with some short-lived isotopes, especially in experiments in which the animals live for some time between injection and death, an oven is used which alternately heats and cools the polymerizing monomer. This oven can be switched on and left unattended for as long as necessary.

The oven was made from a metal meat safe lined with asbestos millboard. Two 500 W heating spirals in series, giving a black heat, were pinned to an asbestos board on the bottom of the oven. An ex-R.A.F. blower was fixed on to the back so that air could be blown into the oven. Three holes were punched in the roof and fitted with thin rubber flaps; these lift and allow air to be blown out through the holes when the fan is on, but close when the heater is on.

The oven circuit was completed as shown in the diagram (Fig. 1) (transformer output 20 V a.c.). A Sectric clock [by S. Smith and Sons (England) Ltd.] (1 rev/min) was geared down to 1 rev/h, and a cam attached to this changed the microswitch from one circuit to another every half-hour. A thermometer was fixed into the oven through a hole in the top, and the thermostat set to 42° C. The monomer is heated in the glass boxes to 42° C for half an hour and then gradually cooled to room temperature, which is reached just before the heater is switched on again. Polymerization is completed in 36 h to 3 days, instead of taking a week or more in an ordinary incubator, from which the boxes have to be removed every half-hour to cool.

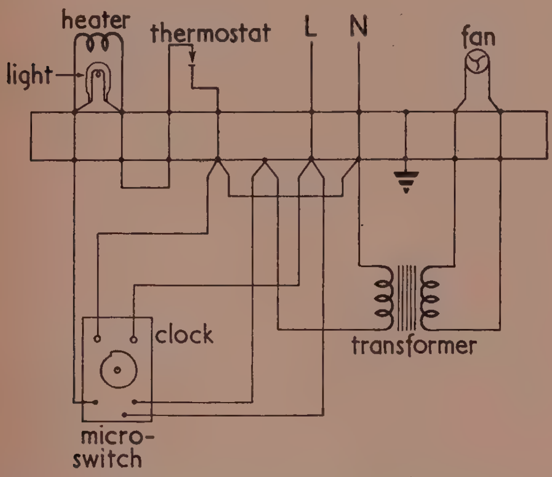


Fig. 1. Diagram of the circuit of the embedding oven

When the monomer has completely polymerized to form Perspex, any loss due to evaporation having been replaced by more monomer, the glass boxes are put into water for half an hour; this allows the glass to be pulled away from the Perspex leaving blocks containing the embedded bones. The blocks are trimmed on a band-saw and stuck on to pieces of wood with Tensol cement (by Thermoplastics Ltd.) which is allowed to harden for 24 h. If speed is essential, as it is when dealing with short-lived radioactive isotopes, the block may be stuck on the wood with partly polymerized monomer which is left for 10 min to allow a skin to form on the surface, and then dropped into a beaker of boiling water, when the monomer hardens and sticks the block to the wood. Thoug rapid, this method does not give such a sure union of bloc and wood as the Tensol cement.

SECTION CUTTING

The blocks are now ready to be cut on the milling machine The machine used is a model OC (by Adcock and Shipley Ltd.), arranged by the makers for climb-milling (i.e. the work moves in the same direction as the cutters); this arrangement produces smooth-surfaced sections and also assists the water into the kerf. A block is clamped into position on the table, the piece of wood fitting into the clamp and the block projecting beneath the saw (see Fig. 2).

After much experimentation the most suitable saws were found to be type H.S.S. screw slitting cutters (by Buck and Hickman Ltd.), $2\frac{3}{4}$ in. in diameter, 0·020 in. in thickness and 16 teeth/in. with a $\frac{1}{2}$ in. bore. These saws are used at 1000 rev/min with a feed of 0·001 in./rev and cooled by a stream of water. During cutting a transparent cover is put over the saw and block to prevent radioactive bone dust and water from spraying the room.

After the initial cut to reach the end of the embedded bone the block is moved forward 625 μ for each section cut; the saw removes 500 μ as dust which, being radioactive, is collected with the water and disposed of in special containers. The sections are put into water in Perspex boxes with numbered cubicles, so that the serial order can be maintained. The sections vary in thickness from 80–150 μ averaging about 100 μ. These are ground down to between 30–50 μ on ground glass under 80% alcohol. The glass is sharpened frequently with 90 grit carborundum. The thickness of the sections is measured with a dial comparator (by J. E. Baty and Co. Ltd.) measuring to 1 μ using a 1 mm diameter foot, thus enabling any variations in thickness of the sections to be detected. The sections must be as even as possible as change in thickness alters the values in the microradiographs. Since the saw removes 500 μ, the sections are 500 μ apart when they are cut. Grinding removes another 50 μ or more, approximately equal quantities being removed from both sides of the sections, so that each section is finally about 550 μ distant from the next serial section. Structures such as Haversian canals and building-sites may be followed, however, from one section to the next. There is, of course, a greater distance between the most distal section of one piece of any bone and the most proximal section of the adjacent piece, since the saw used in dividing the bones into pieces is about 600 μ thick, meaning that there is a distance of 700 μ or more between such sections, but this is unavoidable if embedding is to be efficient. Bones from young or small animals can be embedded without division into three pieces.

AUTORADIOGRAPHS

Autoradiographs are prepared from the sections after microradiographs have been made. The sections are stuck on to an original glass slide with a drop of glycerine-albumen. The surrounding Perspex is softened with chloroform allowing the section to be pressed flat on to the slide with a piece of filter-paper. A drop of absolute alcohol is put on to the section to precipitate the egg-albumen and the section again pressed firmly on to the slide for a few seconds. The slide is then put into a jar of chloroform and left for an hour, when most of the Perspex has been removed from the section. If the Perspex is not dissolved off it tends to make the section curl up and come off the slide. The sections are blotted with

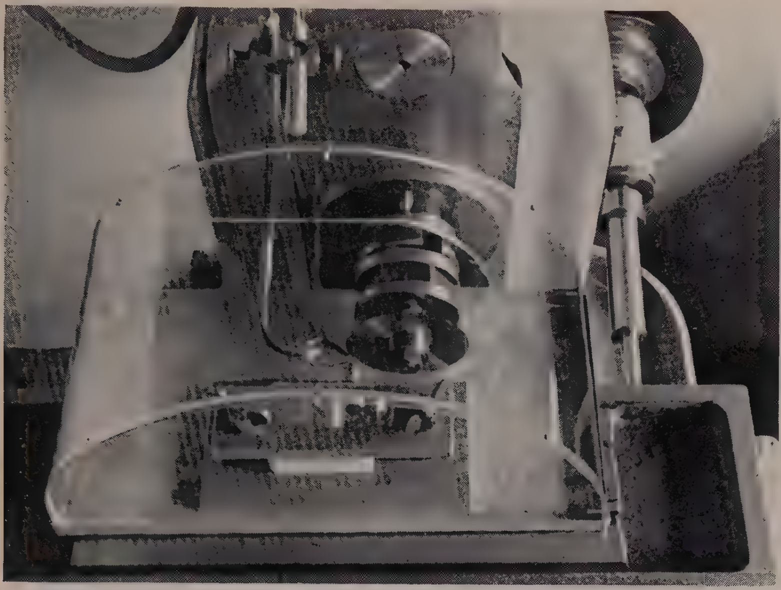


Fig. 2. Milling machine showing an embedded bone ready for cutting

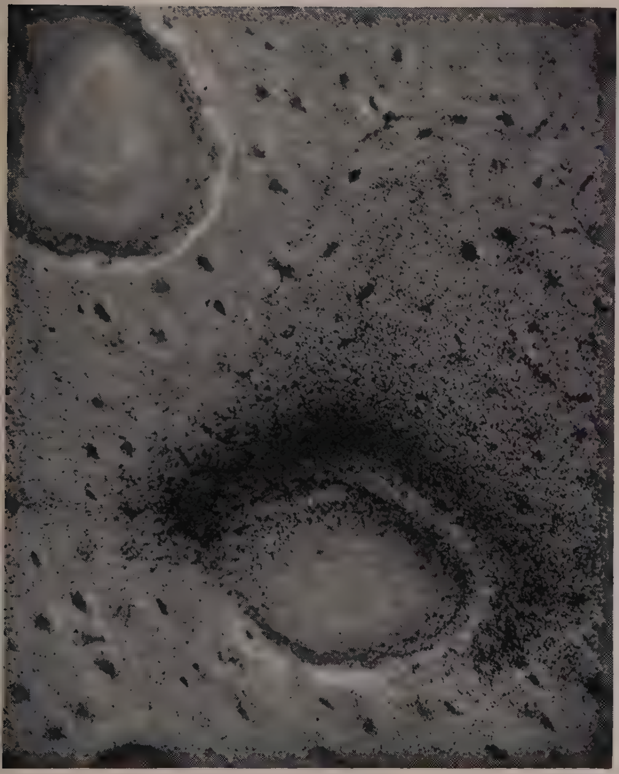


Fig. 3. Microradiograph of a transverse section of a tibia of a monkey aged 4 years, showing an area of low calcification adjacent to a building site. (×200)

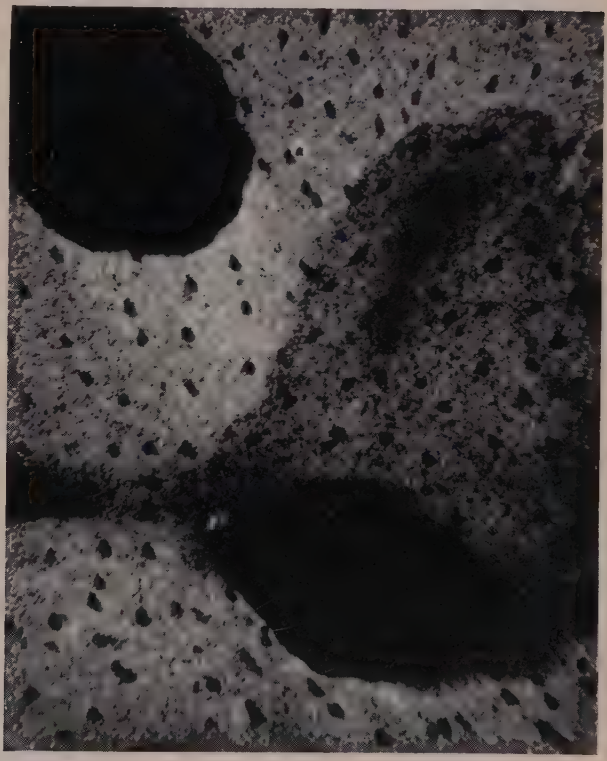


Fig. 4. Autoradiograph of the same section as Fig. 3. (Dose 1000 μc/kg, body weight of ^{90}Sr, exposure time 29 days; fine-grained film.) (×200)

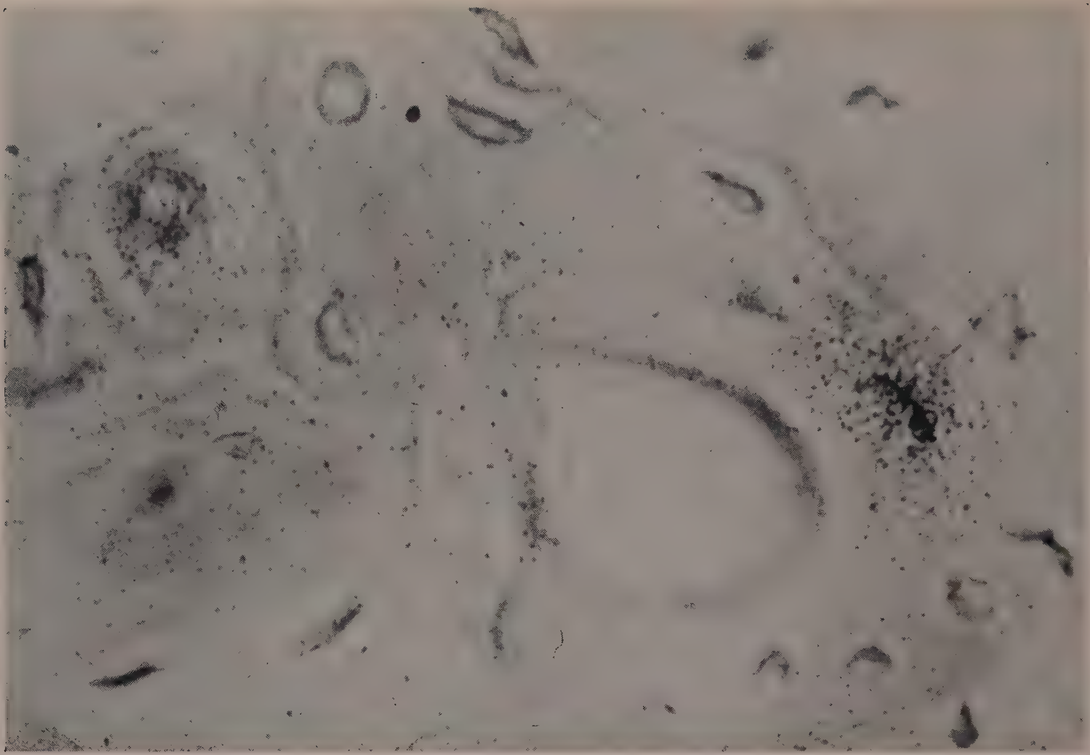


Fig. 5. Autoradiograph of a transverse section of a tibia from a rabbit aged 7 weeks, killed 6 days after injection with 800 μc/kg body weight of ^{91}Y. (Fine-grained film; exposure time 56 days.) (×1000)

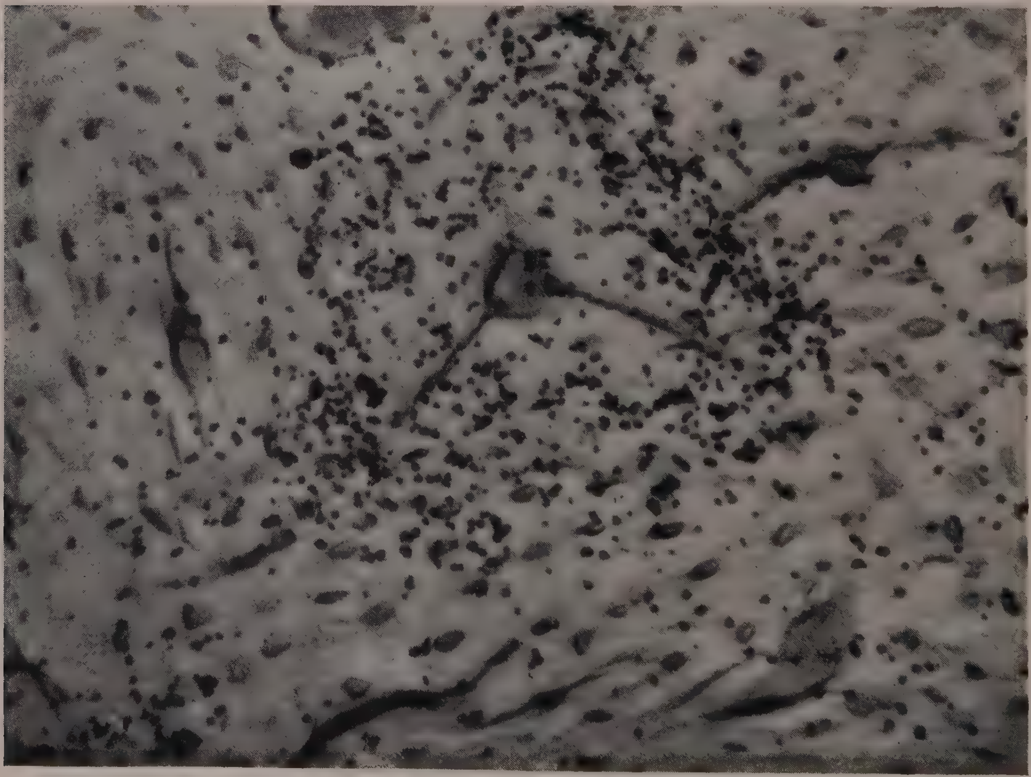


Fig. 6. Autoradiograph of a transverse section of a tibia from a rabbit aged $3\frac{1}{2}$ months, killed 21 days after injection with 3000 μc/kg body weight of ^{35}S. (Large-grained X-ray film; exposure time 18 days.) (×500)

lter-paper soaked in chloroform and the slides cleaned with cid–alcohol. The slides are dipped in ether–alcohol and ien in a 0·5% solution of celloidin in ether–alcohol. The elloidin covers the section with a thin layer and provides a nooth surface for the emulsion. Early work with longiidinal sections uncovered by a layer of celloidin tended to esult in artifacts, an "autoradiograph" forming along ridges n the sections. The first coat of celloidin is allowed to dry or 12 h and the slide is again dipped in the 0·5% celloidin olution, which is allowed to dry for 24 h before floating on ie film. The slides are coated by modifications of the andard method advised by Kodak and developed by oniach and Pelc.(6) Kodak autoradiographic stripping lm, with a fine-grain emulsion 5 μ thick carried on a gelatine ıyer 10 μ thick, is floated on to the section at 25° C from istilled water with approximately 1% glycerine added; this revents the film from drying completely and therefore helps o mitigate pressure effects. The autoradiographs are dried n a stream of air from a fan, and they are stored in slideacks in light-tight boxes that are kept in a refrigerator at ° C for the duration of the exposure time.

The exposure times vary according to the isotope used, the ose the animal receives, its age at the time of injection, the eriod of time it is allowed to live after injection, and, to a ertain extent, to the part of bone from which the section omes; it is impossible to predict the exposure times ccurately, and some sections are taken out as trials after oating at intervals, determined by previous experience. Vith the slow fine-grain emulsion the exposure times have aried from 10 to 60 days with doses of 1000 μc/kg body veight depending on the animal and the experiment. In xperiments with isotopes with soft rays and low bone etention, such as ^{35}S, Kodak experimental stripping film has een used with satisfactory results. This has the same largerained fast emulsion as the X-ray stripping film used for the nacroscopic autoradiographs, in a 4 μ instead of a 12 μ hick layer. It is about ten times as fast as the fine-grained utoradiographic plate usually used, and about half as fast s the X-ray stripping film. It has enabled satisfactory utoradiographs of bone sections containing low doses of ulphur to be taken, whereas the slow film would not register sufficiently strong autoradiograph before the isotope had ecayed.

The autoradiographs are developed and fixed, the film emaining in contact with the specimen. The autoradioraphs are then washed in cold water; the water must be elow 18° C or the film and celloidin layer tend to swell and ome off the slide. The film is then dried slowly at room emperature overnight. Since the sections are relatively thick ompared with sections of soft tissue, and as there are someimes small air bubbles caught in spaces where there is no issue between the celloidin and the film, the autoradiographs re immersed in xylol, mounted in D.P.X. (by The British Drug Houses Ltd.), and cover-slipped. They are then ready or viewing under the microscope.

RESULTS

Similar sections from each animal are always exposed for ifferent times since the optimum exposure varies with the articular problem to be answered. Some sections are lways given a long exposure time so that areas of diffuse ptake are visible and can be compared with heavy localizaions. Details of concentrated uptake are best studied in ections of low exposure times.

High power views of the microradiograph (Fig. 3) and autoradiograph (Fig. 4) from a cross-section of a monkey bone show that there is close correlation between the degree of calcification and the uptake of the isotope ^{90}Sr. The monkey from which this section was taken died 25 days after injection(7) and bone formed between injection and death shows up as a band adjacent to the Haversian canal containing relatively little isotope. The background consists of scatter from areas of heavy reaction and of a diffuse reaction due to uptake throughout mineralized bone.

Higher resolution is possible with the fine-grain emulsion giving fine detail of uptake. With a low exposure time details of uptake over single cells and small vessels may be demonstrated (Fig. 5). Calculations of the number of atoms of the isotope present in small areas, such as over a single osteocyte, may be estimated from such an autoradiograph(8) and the danger to soft tissues in the bone determined.

The fast large-grained emulsion gives a poorer resolution but is necessary if an autoradiograph of an isotope with a short half-life and soft ray, and possibly a low retention, is being investigated. Fig. 6 shows detail of uptake of ^{35}S round a Haversian canal in the cortical bone of a rabbit.

It is difficult to photograph the autoradiographs since at high powers it is impossible to have both the emulsion and the bone section absolutely in focus together, and also any but the most diffuse autoradiograph tends to mask detail of the structure beneath it. The microscope can overcome both these obstacles; the bone is viewed first and then, by raising the objective to the level of the emulsion, the autoradiograph is brought into focus. The method is admittedly laborious but it does enable certain questions, which are of importance both from the point of view of radiation hazards and of normal bone histology, to be answered.(4,5)

ACKNOWLEDGEMENTS

I wish to thank Mr. O. B. Saxby of the Department of Pharmacology, Oxford, for his help in developing this method, and Dr. Herz, Research Department, Kodak Ltd., for his supplies of experimental stripping film and his interest in this problem. This work was begun on behalf of the Protection Sub-committee of the Medical Research Council's committee on Medical and Biological Applications of Nuclear Physics.

REFERENCES

(1) AXELROD, D. *Anat. Rec.*, **98,** p. 19 (1947).

(2) ARNOLD, J. S., and JEE, W. S. S. *Stain Tech.*, **29,** p. 225 (1954).

(3) KIDMAN, B., RAYNER, B., TUTT, M. L., and VAUGHAN, J. M. *J. Path. Bact.*, **64,** p. 453 (1952).

(4) OWEN, M., JOWSEY, J., and VAUGHAN, J. *J. Bone Jt. Surg.* To be published, 1955.

(5) JOWSEY, J., OWEN, M., and VAUGHAN, J. *Brit. J. Exp. Pathology*, **34,** p. 661 (1953).

(6) DONIACH, I., and PELC, S. R. *Brit. J. Radiol.*, **23,** p. 184 (1950).

(7) EDDINGTON, G. M., JUDD, J. M., and WARD, A. H. *Nature* [*London*], **172,** p. 122 (1953).

(8) LAJTHA, L. G. *J. Photogr. Sci.*, **2,** p. 130 (1954).

A simple, sensitive, saturated-core recording magnetometer

By V. B. GERARD, M.Sc., Department of Scientific and Industrial Research, Christchurch, New Zealand

[*Paper received* 22 *December*, 1954]

A versatile saturated-core recording magnetometer, designed to meet a number of geophysical uses, is described. Comparisons with a standard magnetic observatory variometer show that the large amount of negative feedback used keeps the instrument very stable. It has good high-frequency response, and is simple to manufacture and service.

The study of short period geomagnetic fluctuations, with amplitudes of only a few gammas ($1\ \gamma = 10^{-5}$ oersted), is becoming important for advancing geophysical knowledge, and the lack of a suitable magnetometer on which to record them led to the design of the instrument described. Possible relationships between such short period fluctuations and ionospheric phenomena will be investigated when magnetometers of this type are installed at the ionospheric recording stations operated by the New Zealand Department of Scientific and Industrial Research. The same type of magnetometer will be installed at the Volcanological Observatory being built near one of New Zealand's active volcanoes in the Tongariro National Park. Other uses exist in magnetic survey and prospecting work, as, for instance, when aeromagnetic or surface magnetic prospecting requires a continuous record of the diurnal variation of a particular component of the earth's field.

While it is true that conventional magnetic variometers, used at magnetic observatories for decades, can meet some of these requirements, they lack the versatility and robustness of this electronic instrument. It has the advantages of visual recording of any desired component, much better frequency response, and a selection of sensitivity ranges. It is not easily damaged during handling and can be set up to operate in a few minutes. On the other hand, the conventional variometer has the advantage of extreme stability and reliability.

In designing this instrument the aim has been to keep it simple electronically, so that it would be easy to manufacture and service, but at the same time to make it as versatile as possible. Two versions of the magnetometer have been designed. One is portable, and intended for operation from dry batteries, for periods of up to a few days, at locations where electric power is not available. This version, which is the one described below, has a total power consumption of only 4 W. The other instrument is designed for operation from a.c. mains, and consumes about 50 W. Electronically both versions are almost identical, except for the valve types used.

The saturated-core method has been widely used in aeromagnetometers, submarine detectors, fluxgate compasses, etc., for use in aircraft, but it does not appear to have been used greatly in magnetometers intended for use on the ground. However, at least one such instrument has been described by Rose and Bloom.(1) Their instrument appears to be relatively complicated and to have other disadvantages, such as somewhat high power consumption and poor high-frequency response. It was decided that it could not easily be modified to meet all the present requirements, and that it would be better to design a new instrument.

THE PRINCIPLE OF THE MAGNETOMETER

As the principle of operation of the saturated core magnetometer is well known, and as a good description has been given by Felch and others,(2) it will only be described briefly here. A straight core, consisting of a wire or narrow stri of a high permeability alloy, such as Permalloy C or Mu metal, is excited by a sinusoidal field of sufficient amplitud to drive it well into saturation each half cycle. The resultin voltage waveform, induced in a coil around the core, i distorted, and contains even and odd harmonics of th driving frequency. The amplitudes of the harmonics ar functions of the ambient magnetic field along the core. A the amplitude of the second harmonic is roughly proportiona to the ambient field, it is usual to separate this harmoni from the others by means of a filter, and measure its amplitude thus obtaining a measure of the unknown magnetic field.

The detector element of the instrument described below uses two parallel cores excited in opposition. A common secondary is wound around both and this feeds the filter The voltages induced in the secondary due to the fundamental and any second harmonic present in the driving waveform are very much reduced by using the two-core method. Hence the separation of the wanted second harmonic is less difficult The output of the filter is amplified, rectified by a phase sensitive detector, and amplified again by a d.c. amplifier which operates the recorder.

The recorder current also passes through another coi wound around the detector element, to provide overal negative feedback. By this means, both the linearity and the stability of the instrument are greatly improved. The amoun of feedback that can be used depends on the high-frequency response required. This is because the feedback loop mus satisfy the requirement that the transmission around it is less than unity when the phase shift reaches 180°. It was considered desirable to provide for a frequency response extending to about 20 c/s, although for much work this would be quite unnecessary, and would require a high-speed recorder Stability requirements make it desirable to use as much feedback as possible, and, for a given high-frequency response it may be shown that the wider the pass band of the filter the greater is the amount of feedback that may be used before the feedback loop oscillates. Accordingly, the pass band of the filter was made as wide as possible, and extends from just above the fundamental to just below the third harmonic.

THE INSTRUMENT

Fig. 1 shows the circuit diagram of the instrument. The cores of the detector element consist of Permalloy C tubes, 4 in. long and $\frac{1}{16}$ in. diameter, comprising one complete turn of 0·001 in. strip. These were supplied in a fully heat-treated condition by Standard Telephones and Cables Ltd. The cores are enclosed in Pyrex glass tubes, on which are wound the various coils, each also 4 in. long.

The exciting frequency of 400 c/s is derived from an resistance-capacitance oscillator of unusual design.(3) There is no reason why any other oscillator circuit should not be used, providing it has a good waveform and good frequency stability. Between the oscillator valve, V_1, and the triode, V_3 which drives the detector element, is an amplifier stage, V_2

hich has its gain varied by an automatic gain control voltage order to keep the amplitude of the driving field constant. lthough V_2 is operated near cut-off, the amplitude of the ternating voltage on its grid is sufficiently small to keep stortion reasonably low.

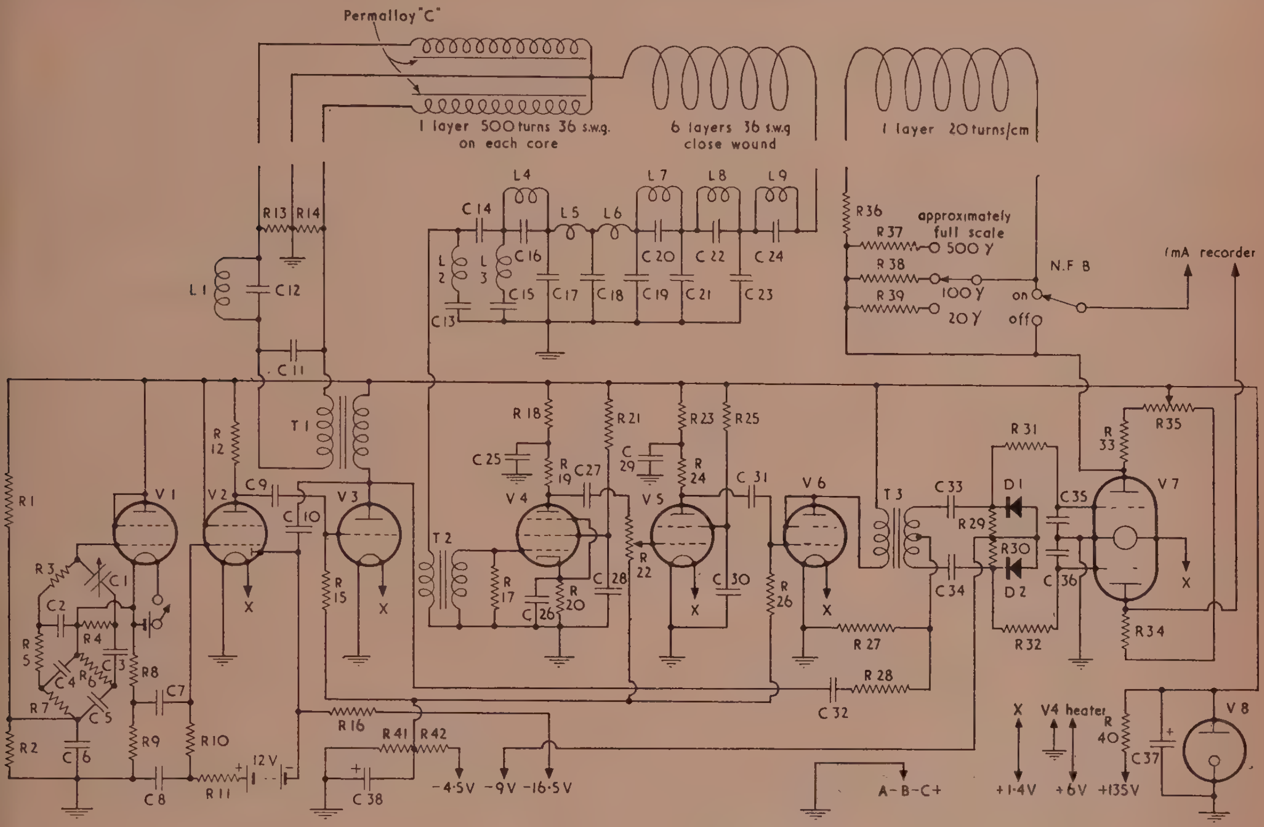

Permalloy "C"
1 layer 500 turns 36 s.w.g. on each core
6 layers 36 s.w.g close wound
1 layer 20 turns/cm
L4
L7
L8
L9
C14
L5
L6
L2
L3
C16
C20
C22
C24
C13
C15
C17
C18
C19
C21
C23
R13
R14
L1
C12
C11
R36
approximately full scale
R37
500 γ
R38
R39
100 γ
20 γ
N.F.B
on
off
1mA recorder
T1
R12
R1
V1
V2
C9
V3
C10
R3
C1
C2
R4
R5
C4
R6
C3
R8
R7
C5
C7
R2
C6
R9
R10
C8
R11
12 V
X
R15
T2
R18
C25
R19
C27
V4
R17
C26
R20
C28
R21
C29
R24
R22
V5
R23
R25
C30
C31
V6
R26
T3
C33
C34
R29
R30
D1
D2
R31
R32
C35
C36
R33
R35
V7
R34
R27
R28
C32
R16
R41
R42
C38
−4·5V −9V −16·5V
A−B−C+
X
V4 heater
R40
C37
V8
+1·4V +6V +135V

Fig. 1. Magnetometer circuit diagram

R_1 = 300 kΩ
R_2 = 20 kΩ
R_3 = 4 MΩ, high stability
R_4, R_5 = 500 kΩ, high stability
R_6, R_7 = 50 kΩ, high stability
R_8 = 15 kΩ
R_9 = 500 Ω
R_{10} = 500 k
R_{11} = 5 MΩ
R_{12} = 200 kΩ
R_{13}, R_{14} = 50 Ω
R_{15}, R_{16} = 500 kΩ
R_{17} = 100 kΩ
R_{18} = 50 kΩ
R_{19} = 1 MΩ
R_{20} = 8 kΩ
R_{21} = 3 MΩ
R_{22} = 3 MΩ potentiometer
R_{23} = 100 kΩ
R_{24} = 1 MΩ
R_{25} = 3 MΩ
R_{26} = 5 MΩ
R_{27} = 20 kΩ
R_{28} = 6 k

R_{29}, R_{30} = 500 kΩ
R_{31}, R_{32} = 5 MΩ
R_{33}, R_{34} = 10 kΩ
R_{35}, 5 kΩ potentiometer
R_{36} = 250 Ω
R_{37} = 63 Ω
R_{38} = 10·4 Ω
R_{39} = 2·0 Ω
R_{40} = 2·7 kΩ
R_{41} = 56 kΩ
R_{42} = 44 kΩ

L_1 = 72·8 mH
L_2, L_3 = 0·530 H
L_4 = 76·5 mH
L_5, L_6 = 0·306 H
L_7 = 0·232 H
L_8 = 0·153 H
L_9 = 76·5 mH

V_1, V_2 = 1U5
V_3 = ½3A5
V_4 = EF86

V_5, V_6 = 1U5
V_7 = 3A5
V_8 = 85A2

C_1 = 80–120 pF variable
C_2, C_3 = 800 pF high stability
C_4, C_5 = 8 000 pF high stability
C_6 = 1 μF
C_7 = 0·01 μF
C_8 = 0·25 μF
C_9 = 0·01 μF
C_{10} = 0·05 μF
C_{11} = 1·62 μF
C_{12} = 0·54 μF
C_{13} = 0·298 μF
C_{14} = 0·265 μF
C_{15} = 0·298 μF
C_{16} = 0·230 μF
C_{17} = 0·2295 μF
C_{18} = 0·306 μF
C_{19} = 0·269 μF
C_{20} = 0·0425 μF
C_{21} = 0·1925 μF
C_{22} = 0·115 μF

C_{23} = 0·153 μF
C_{24} = 0·230μF
C_{25}, C_{26} = 1 μF
C_{27} = 250 pF
C_{28} = 0·1 μF
C_{29} = 0·05 μF
C_{30} = 0·1 μF
C_{31} = 200 pF
C_{32}, C_{33}, C_{34} = 0·02 μF
C_{35}, C_{36} = 0·05 μF
C_{37} = 16 μF
C_{38} = 25 μF

T_1 = primary 12 000 Ω,
secondary 3 000 Ω
T_2 = primary 1 000 Ω,
secondary 100 000 Ω
T_3 = primary 20 000 Ω,
secondary 80 000 Ω, centre tap

D_1, D_2 = S.T.C. type M1

N.F.B. = negative feedback

The detector element is driven through a simple impedance atching network, C_{11}, L_1, C_{12}. L_1 is wound on a Ferroxcube ot core, type No. D45/39 26.70 III B4. This network atches the 3 000 Ω output impedance of the transformer , to the input impedance of the detector element, which about 20 Ω. However, the main purpose of the network to act as a filter to reduce the amount of second harmonic the driving waveform. Although the alternating voltage duced in the secondary, due to second harmonic present the driving waveform, is greatly reduced by using the o-core detector, it does not seem to be possible to obtain cores which balance sufficiently well to avoid the need for some filtering of the driving waveform.

The secondary winding of the detector element has its output filtered by the 1 000 Ω filter L_2, C_{13}, . . . L_9, C_{24}. Fig. 2 shows the attenuation-frequency characteristic of this filter. The inductances are wound on Ferroxcube pot cores, type No. D36/22 9.80 III B1.

To avoid the microphonic noise normally generated by a valve with a directly heated cathode, the first stage of the amplifier, following the filter, uses an indirectly heated valve, V_4. Unfortunately, its heater consumes 1¼ W, which is a large fraction of the total power consumption of 4 W.

The phase-sensitive detector, which follows the amplifier, is rather unusual because the frequency of the reference voltage is half the frequency of the signal. For proper operation, the diodes of the detector must operate as peak rectifiers. Fig. 3 shows how the signal and reference voltages, applied to each diode, combine to give a waveform the peak height of which depends on the amplitude of the signal. This phase-sensitive detector has the advantage that a frequency doubler to provide the reference voltage is unnecessary.

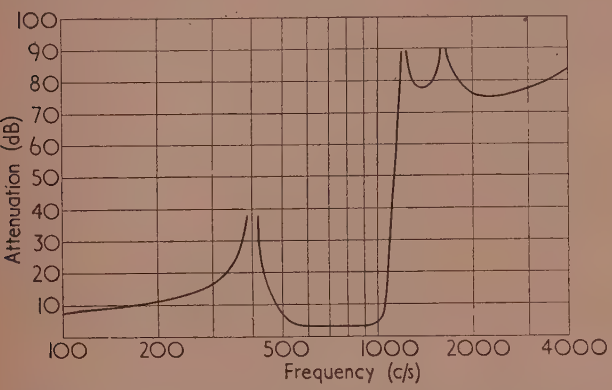


Fig. 2. Attenuation/frequency characteristic of the filter, *L2*, *C13*, . . . *L9*, *C24*, which removes unwanted harmonics from the output of the detector element

The phase-sensitive detector drives the push-pull output stage, V_7, through a resistance-capacitance filter. V_7 operates the recorder, and the recorder current also flows through the feedback coil. The amount of feedback determines the sensitivity of the instrument, and, by switching shunts across the feedback coil, a series of sensitivities is provided. The amount of filtering needed after the phase-sensitive detector, and provided by R_{31}, C_{35}, and R_{32}, C_{36}, is fixed by the frequency response and the amount of feedback that is desired. The time constants $R_{31}C_{35}$, and $R_{32}C_{36}$, are equal, and, if they are reduced, then the high-frequency response improves, but the maximum permissible feedback decreases. However, it is easy to obtain a good compromise between these two conflicting requirements. For instance, the values of R_{31}, C_{35}, and R_{32}, C_{36}, shown in Fig. 1 permit gain reductions due to feedback of about 40 dB, while the frequency response is better than that of an ordinary 1 mA recorder (by Esterline-Angus Co. Inc.). In general, the type of recorder to be used, and the use to which the instrument is to be put, determine the best value of the time constants, $R_{31}C_{35}$, and $R_{32}C_{36}$. The most suitable value is perhaps best found by experiment, but may also be calculated if the phase characteristic of the filter, L_2, C_{13}, . . . L_9, C_{24}, is known.

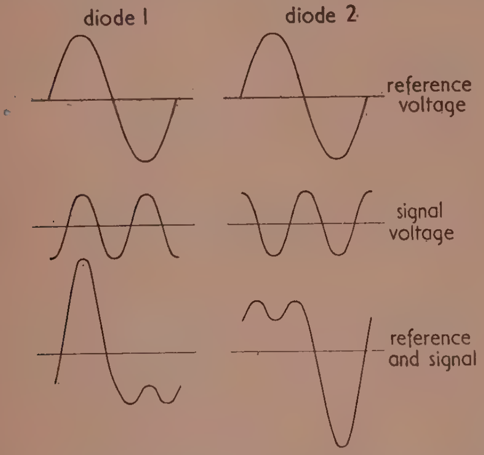


Fig. 3. Voltage waveforms applied to the diodes of the phase-sensitive detector

Without feedback, the maximum sensitivity of the instrument is about 4 γ per mA recorder current. Hence, using a 1 mA Esterline Angus recorder the detector element is normally never more than ±2 γ off balance. For much work it is convenient to operate the instrument so that a change of 1 mA in recorder current corresponds to 100 γ change in ambient field. Under these conditions the feedback is large enough to make quite large changes in the gain of the amplifiers have negligible effect on the indicated reading.

For some purposes it may be found that the recorder range is insufficient to record large changes at the desired sensitivity. This can be overcome in the following way. When the recorder pen reaches either side of the paper it closes a contact which operates a stepping switch and switches a direct current through a coil around the detector element. This current produces a magnetic field of the proper magnitude and sig to bring the pen back on to the paper.

PERFORMANCE AND TESTS

The instrument was tested by operating it at the Amberley Magnetic Observatory and comparing its record with the Observatory magnetograms. Fig. 4 shows a typical record and the corresponding magnetogram during a magnetically quiet period. The component recorded is declination, bu any other component may be recorded if the field along the detector element is reduced to zero by means of an applied field. The agreement between the two records is excellen and, by comparison between these and other records, it was found that the drift and temperature coefficient of the magnetometer are negligible for most purposes.

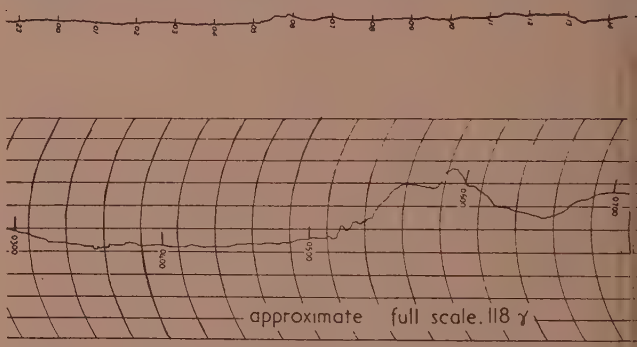


Fig. 4. Corresponding records taken at Amberley Magnetic Observatory with saturated core magnetometer (lower) and standard observatory variometer (upper). Time marks are G.m.t., but the time scales are different. The component recorded is declination

ACKNOWLEDGEMENT

The writer wishes to thank Messrs. C. J. Banwell an B. H. Olsson of the Dominion Physical Laboratory, Lowe Hutt, for helpful discussions.

REFERENCES

(1) ROSE, D. C., and BLOOM, J. N. *Canad. J. Res.* *A*, **28** p. 153 (1950).
(2) FELCH, E. P., MEANS, W. J., SLONCZEWSKI, T., PARRATT L. G., RUMBAUGH, L. H., and TICKNER, A. J. *Tran Amer. Inst. Elect. Engrs*, **66**, p. 641 (1947).
(3) BACON, W., and SALMON, D. P. *Wireless Engr*, **30**, p. 2 (1953).

An infra-red radiation pyrometer

By J. D. Harmer, B.Sc., A.M.I.E.E., and B. N. Watts, B.Sc., A.Inst.P., The British Thomson-Houston Co. Ltd., Rugby

[*Paper first received* 23 *December*, 1954, *and in final form* 4 *February*, 1955]

The construction of a general purpose radiation pyrometer using a lead sulphide photocell is described. Based on a comparison principle, the instrument is independent of ambient temperature variations. The temperature range covered is 200–1000° C with an accuracy of ±5° C and a response time of less than 0·1 s.

he measurement of surface temperature under conditions which normal methods of contact pyrometry are not pplicable, may be achieved by either chemical methods or by easurement of the emitted radiation. The use of chemical eans, such as the colour changes in certain pigments with emperature, affords a very valuable technique, but has bvious limitations. The possibilities of radiation pyrometry ave long been recognized, but its development has been rgely handicapped by the lack of suitable radiation etectors.

A number of instruments, such as that described by Land(1) ave used photo-emissive or photo-voltaic cells. This ethod has the advantage of rapid response, but is limited to e higher range of temperatures, greater than 600° C, by e maximum wavelength response of the cell, about 1·3 μ r cells of the caesium oxide type. The potentialities of the tal radiation type of receiver, such as the radiation thermoile and the bolometer, have also been exploited.(2) In ese cases, although the minimum detectable temperature is ery low, the response time of the detector is too slow for any important applications.

The possibilities of using lead sulphide photoconductive ells (sensitive to about 3 μ) for high-speed low-temperature yrometry were first pointed out by Lee and Parker.(3) Later arker and Marshall(4) used such a cell in an investigation to the temperature of locomotive tyres under conditions of evere braking. Subsequently, several investigators have onstructed temperature measuring equipment based on the ad sulphide cell to fill their individual needs.

PRINCIPLES OF CONSTRUCTION

It has long been recognized that, as pointed out by Carlisle nd Alderton(5) one of the chief difficulties in the use of lead lphide photoconductive cells for the precise measurement f radiation is their large temperature coefficient of sensitivity. his produces a decrease in cell output of approximately 7% r each degree rise in cell temperature. It should be recognized that this difficulty is inherent in any type of photoectric device which is responsive to long wavelength infra-d radiation. However, this difficulty can be overcome ithout resort to elaborate thermostatic devices by using the ll only as a null detector. By this means the temperature easurement can be made independent of the absolute nsitivity of the cell. One method of achieving this is to mpare the radiation from the unknown source with that om an adjustable and known comparison source. When e two beams of radiation produce equal outputs from the ll, the intensity of the unknown radiation is known relative the comparison source: hence, only the precision of the easurement depends on the sensitivity of the cell. One ad suphide cell pyrometer of this type has been described Pyatt.(6)

In the present instrument, the primary beam of radiation asses through a rotating sector disk, driven by a small synchronous motor, which interrupts the radiation at a frequency of 1000 c/s. Radiation from the comparison source is reflected from the back of the opaque vanes of this sector disk. This radiation is, therefore, modulated out of phase by 180° with the primary radiation. The power input to the comparison source can then be adjusted to give equal intensity at the cell from both beams.

Another major objection to all radiation pyrometers is their dependence on the emissivity of the surface being measured. Gibson(7) in his pyrometer, has attempted to overcome this difficulty by taking the ratio of the signals in two different wavelength bands. This adds greatly to the complexity of the instrument and the widespread use of the optical pyrometer illustrates that equivalent black-body temperature is a very useful criterion in a great many temperature measurement problems.

DESCRIPTION OF INSTRUMENT

The present instrument as shown in Fig 1 is composed of two parts, the viewing head and the electronic control box. In many applications it is convenient to have these separated by considerable distances so that the actual temperature readings are taken at a point remote from the object being studied.

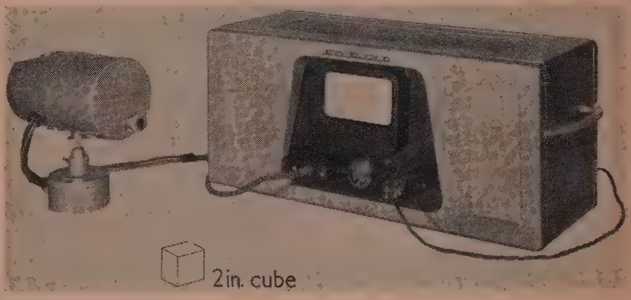


Fig. 1. Pyrometer head and control box

Viewing head. A view of the layout of the head is shown in Fig.2. Borosilicate glass lenses were used throughout the optical system in the pyrometer, since the increased energy available with materials having a longer wavelength cut-off is only small when using a lead sulphide photocell. This glass transmits only wavelengths which are photoelectrically effective at the cell. Longer wavelength radiation has the undesirable effect of heating the cell surface without increasing the signal.

The optical system is shown in Fig. 3, lens L_1 images the source S_1 in the plane of the diaphragm D. The shape and size of the aperture in this diaphragm then determines the area of the source to be viewed. In the present instrument this is a rectangle 10 × 1 mm, but it can be easily adjusted to suit any particular application. The image of the aperture is produced by lens L_2 with unit magnification in the plane of the sensitive surface of the photocell. Therefore the sensitive area of the photocell sets the upper limit to the maximum size of useful aperture in D. The area of the object viewed is the size of the aperture in D as magnified by L_1 in the plane of the source. Hence the temperature indication is independent of the distance of the source from the pyrometer, providing that the aperture is always filled. The focusing of L_1 is arranged by displacing both the photocell and the diaphragm D from the axis of the optical system and viewing the image formed on a ground glass screen in the plane of the diaphragm. The diaphragm D is displaced to allow more light to reach the screen and to provide a larger field of view to facilitate the positioning of the pyrometer.

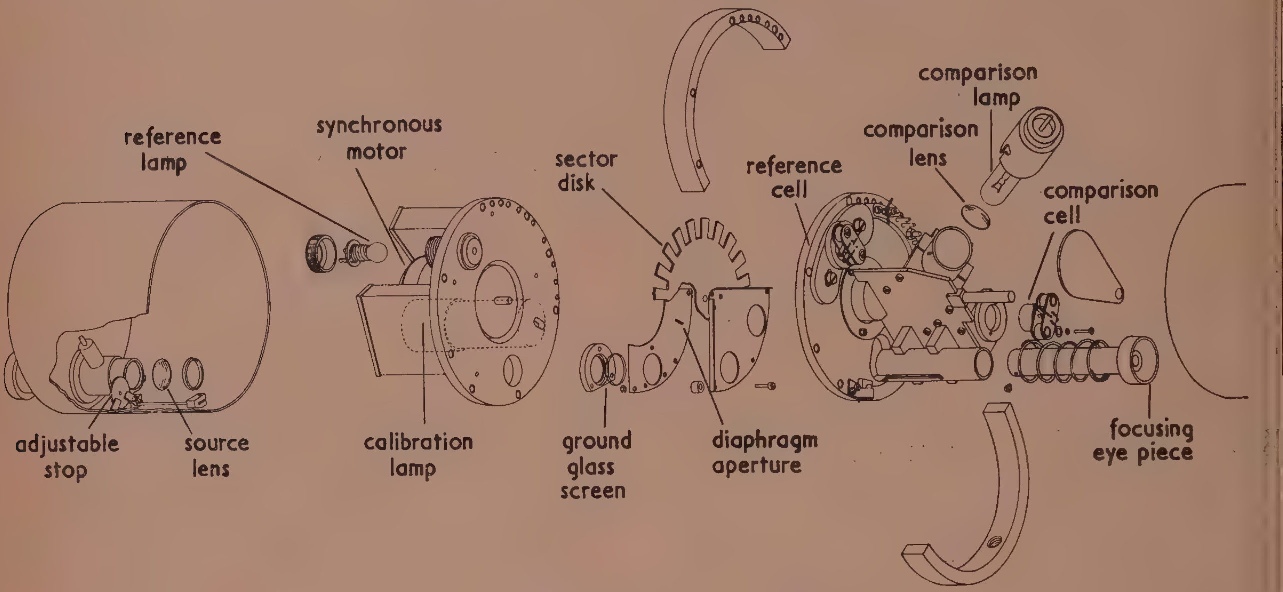


Fig. 2. Layout of pyrometer head

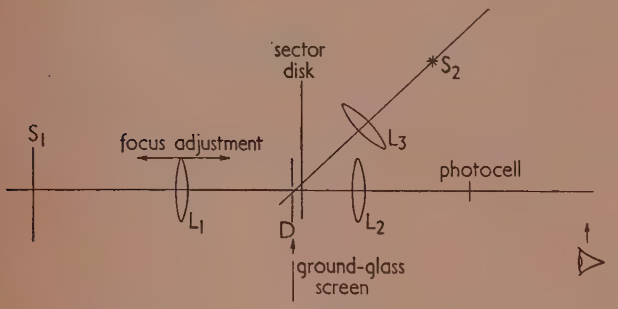


Fig. 3. Optical system of viewing head

The lens L_3 focusing the radiation from the comparison source S_2 is adjusted to form a uniform illumination of the rear of the aperture in D. This radiation is then diffusely reflected by the vanes of the sector disk, which are painted matt white, and focused by the lens L_2 on the sensitive surface of the photocell. The chopper disk is arranged to be as close as mechanically possible behind the diaphragm. The remainder of the inside of the head is painted a matt black to eliminate stray reflexions.

Comparison source. The radiation source used as the comparator is a tungsten filament projector lamp type 1884C These lamps have been carefully selected to fulfil a close specification of colour temperature against applied voltage To maintain this calibration during life, precautions are taken so that this lamp is never run at greater than 80% o the nominal rating. This also has the considerable advantage of greatly extending the life of the lamp.

Feedback control of the comparison source. The power fed to the comparison source is adjusted automatically by a feedback control to make the radiation from this balance the radiation from the source of unknown temperature. Fig. 4 is a block diagram showing the function of each part of the control system.

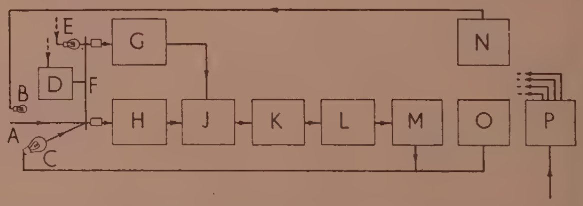


Fig. 4. Block diagram of infra-red radiation pyrometer

A, source; *B*, calibration lamp; *C*, comparator lamp; *D*, motor; *E*, reference lamp; *F*, sector disk; *G*, reference amplifier; *H*, error amplifier; *J*, phase-sensitive demodulator; *K*, compensating circuit; *L*, d.c. amplifier; *M*, magnetic amplifier; *N*, calibration supply; *O*, meter and controller; *P*, power supply and stabilizer.

If there is any difference in the radiation from the source and the comparator lamp, the radiation falling on the lead sulphide cell is modulated between these two levels by the chopper disk. The resulting 1000 c/s signal from the cell is fed through the error amplifier (Fig. 4) and rectified by a phase sensitive demodulator to provide a d.c. control voltage proportional to the out-of-balance radiation or "error." The error amplifier comprises two electronic stages with a positive frequency sensitive feedback which provide a voltage gain of 3000 at 1000 c/s and a bandwidth of 100 c/s. *A* nchronous reference signal for phase sensitive rectification provided by chopping the radiation from a small reference mp at another point round the sector disk, and irradiating second cell with this. This signal is amplified in the ference amplifier to produce a square wave output. This gnal is fed in paraphase to two diamond circuits of rmanium rectifiers, connected so that a balanced push-pull c. output is obtained from the demodulator.

After passing through a compensating circuit and a single age push-pull d.c. amplifier, the error signal drives the ntrol windings of a magnetic amplifier which adjusts the) c/s power fed to the comparator lamp.

The significant time effects in the feedback system are the ermal time constant of the comparator lamp (about 0·15 s) nd a small time delay in the phase sensitive demodulator nd magnetic amplifier. A compensating circuit is provided replace the lamp time constant with one of 3 s. Under ese conditions the system is stable when the full loop gain 100 times is used. The transient response to small disrbances is well damped and settles in a fraction of a second. he pyrometer will follow a continuously changing temperare with a time lag of only 0·1 s. The time for an accurate etermination of temperature upon sudden exposure to conitions giving a full-scale deflexion of the meter is about 2 s.

The radiation temperature of the source is observed from calibrated meter on the control box which measures the oltage across the comparator lamp. Two temperature ales (determined by an adjustable stop associated with the ource lens L_1 in Fig. 3), cover the range of temperature from nder 200° C to approximately 1000° C with an accuracy of ± 5° C. Higher ranges can be covered by a further reduction the aperture of L_1 or by the use of filters.

Temperature control relay. A controller circuit is provided hich operates a relay when any pre-set temperature is eached. This circuit includes a bistable triggered pulse enerator operated by the difference between a reference oltage and that across the meter. By depressing a switch, ne reference voltage is observed directly by the same meter hich indicates temperature. This affords a convenient eans of pre-setting the temperature at which the control is equired to operate. A differential control enables the emperature drop before the control relay returns to its itial condition to be adjusted from a minimum of 10° C to ny higher increment. Two relay contacts, one normally pen and the other normally closed, are provided, and onnected to independent pairs of terminals at the back of ne control box. The contacts can operate in circuits of up 440 V and 1 A a.c.

CALIBRATION

The calibration of the instrument is carried out in a quite rbitrary manner using a specially constructed black-body. part from electronic faults, the only sources of error roducing subsequent inaccuracies in this calibration are nanges in the lamp characteristic, which have been dealt ith already, and deposits of dirt on the lenses and the white rfaces of the opaque sectors. The lenses can be easily eaned when necessary. Changes in the reflectivity of the ctors can be detected by using a standard calibration test ource. Such a source, again a carefully selected and conderably under-run filament lamp, is built into the pyrometer ead. When this source is swung into position the pyrometer hould read a pre-set temperature. If the pyrometer reads igh, then the reflectivity of the sectors has fallen and they eed repainting. Experience has shown that repainting is only required very occasionally, even in dirty atmospheres. When repainting is required, the best results are obtained using a magnesium oxide base paint, as is normally used in photometric laboratories for integrating spheres.

EMISSIVITY CORRECTION

No attempt has been made to make any correction for the departure from black-body conditions in this instrument. In most cases it is comparative measurements or a reproduction of previous conditions which provide the main interest. If an accurate determination of the temperature of the body is required, the emissivity correction and its variation with temperature can usually be obtained as a separate experiment.

The emissivity correction, using a lead sulphide photocell as the detector, is usually quite small. Fig. 5 shows the signal output as a function of source temperature. It will be seen that the output signal V, is proportional to T^n where $n > 4$ and is as high as $10 - 12$ at low temperatures. Therefore, if T_B is the equivalent black-body temperature we have:

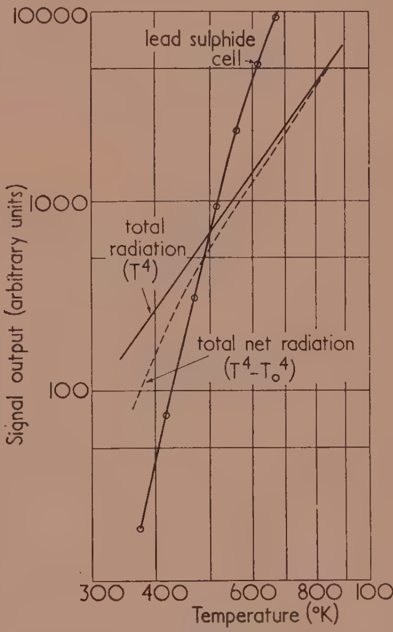


Fig. 5. Variation of signal with change of source temperature for a lead sulphide photocell

$$V = \epsilon T^n = T_B{}^n$$

Then $$T = T_B / \sqrt[n]{\epsilon}$$

Another factor which should be considered along with the emissivity correction is that of background illumination. If the surface of the target has a high reflectivity and hence a low emissivity, e.g. aluminium sheet, the radiation reflected from the surface at high illumination levels may be comparable with the true heat radiation at low temperatures.

CONCLUSIONS

This instrument, with its rapid response and continuous indication, should enable many temperature measurements to be made for which other instruments are not suitable. It should be particularly useful when the temperature is required of an object which is inaccessible because it is in rapid motion, at a high voltage or enclosed in a transparent envelope. Examples of such applications are controlling the temperature of a work-piece heated by high frequency currents, and measuring the temperature of electrodes in high-power valves.

ACKNOWLEDGEMENTS

The authors are most grateful to Messrs. J. R. Howells and P. F. Griffin for their assistance in designing and constructing this pyrometer. They would like also to thank Mr. L. J. Davies, Director of Research, The British-Thomson-Houston Company, Ltd, for permission to publish this paper.

REFERENCES

(1) Land, T. *J. Iron Steel Inst.*, **149**, p. 481 (1944).
(2) Mouzon, J. G., and Dyer, C. A. *J. Opt. Soc. Amer.* **39**, p. 204 (1949).
(3) Lee, E., and Parker, R. C. *Nature* [London], **158**, p. 51 (1946).
(4) Parker, R. C., and Marshall, P. R., *Proc. Instn. Mech Engrs*, **158**, p. 209 (1948).
(5) Carlisle, S. S., and Alderton, G. *Nature* [London] **163**, p. 529 (1949).
(6) Pyatt, E. C. *J. Sci. Instrum.*, **29**, p. 125 (1952).
(7) Gibson, A. F. *J. Sci. Instrum.*, **28**, p. 153 (1951).

A microscope hot stage using electron bombardment

By G. J. Ogilvie, Ph.D., and G. Brinson, B.Sc., Division of Tribophysics, Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia

[*Paper received* 10 *December*, 1954]

A microscope hot stage is described for use with metal specimens. The specimen is supported in a vacuum between three pointed wires, two of which are the elements of a thermocouple, and heated by electron bombardment. In this way very rapid heating of the specimen is possible with full control of temperature and with very small power inputs.

Until now microscope hot stages for metallurgical specimens have fallen into two general classes; the specimen is heated either by a resistance-wound furnace$^{(1-9)}$ or by passing a current through it. In many investigations rapid and controlled heating of the specimen to the operating temperature is essential. This requirement can be most easily met by generating heat at or in the specimen itself. The only designs of this type are those due to Williams$^{(10)}$ and Cech.$^{(11)}$ Any hot stage in which the specimen is heated directly by passing a current through it$^{(10,11)}$ suffers from the disadvantage that the heavy-current leads conduct away much of the heat generated, and, as a result, the specimen temperature is not uniform.

In the design to be described heat is generated at the specimen surface by electron bombardment, thus eliminating the need for heavy-current leads to the specimen.

DESIGN

In this design (which is intended for an inverted type microscope) the specimen is supported between three pointed wires. A high potential is established between the specimen and a filament placed close to it, the filament being made negative with respect to the specimen. The electron current which flows when the filament is hot generates heat at the specimen surface.

A water-cooled chamber (see the figure) is held on the microscope stage by screws passing through the flange. The upper end of the chamber is closed by a glass plate *A* sealed with an O-ring. The window *B* (a No. 1 cover slip) is cemented in position with Araldite type 101 cold-setting resin.

Leads are taken through the chamber walls in silica tubes cemented in position with Araldite type 1 hot-setting resin. The high vacuum line *C* and the connexion for the vacuum gauge *D* also pass through the wall of the chamber. The high vacuum line is a short rigid tube and carries at its outer end a liquid air trap *E* which supports in turn a small mercury diffusion pump [type 1M1 by W. Edwards and Co. (London Ltd.]. The glass tube *F* in the cold trap which contains the liquid air is cemented in position with Araldite resin type 1 The high vacuum line is made just sufficiently long to hold the diffusion pump assembly clear of the microscope to allow an unimpeded rotation of the stage through at least 90°. A separate insert *G* is located in the bottom of the chamber and carries the specimen and the filament assembly. The specimen is clipped between the pointed ends of the two insulated wires of a chromel-alumel thermocouple and the pointed end of a tungsten wire, which acts as a spring so as to force the specimen firmly against the wires of the thermocouple. A convenient filament is that of a 2·5 V 0·5 A lamp with the glass bulb removed and it is carried by leads soldered to its base. These leads pass through two short lengths of silica tube cemented to the insert. Electrical connexion to the insert can be made rapidly by soldering to the external leads provided that the thermocouple wires have been previously "tinned."

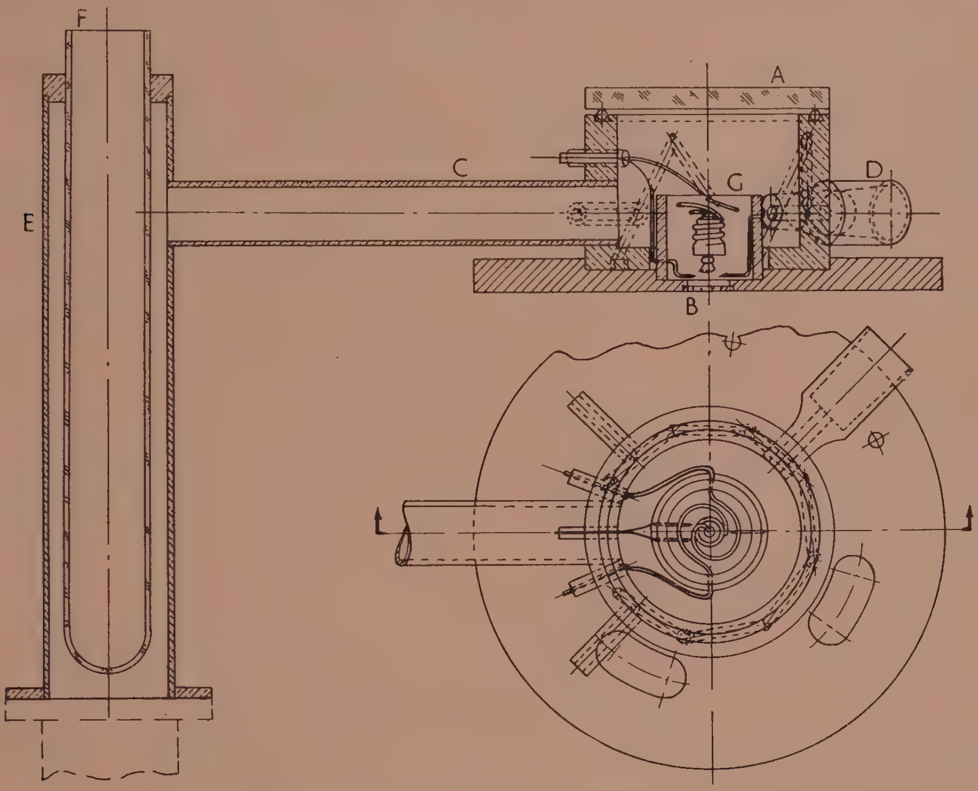
A convenient value for the high tension is 1000 V. The supply should preferably be d.c. so that the filament temperature for a given electron current is a minimum. An accumulator with a series rheostat makes a simple and very stable supply for the filament. Adjustment of the heat input to the specimen is made by alteration of the heating current in the filament only. The specimen should not be further than ¼ in. from the filament with a h.t. of 1000 V, or space charge limitation of the current takes place. A convenient separation is approximately ⅛ in.

PERFORMANCE

In practice, extremely rapid rates of heating are possible. The full possibilities have not been explored but a rate of approximately 2000° C/min (over the temperature range

–200° C) has been used for a zinc specimen approximately × 12 × 1 mm and much higher rates are feasible without ange in the design.

Since the specimen is effectively isolated in vacuum and e heat is generated at its surface, the response to a change power input is extremely rapid. Thus, in practice, if the ower input to maintain a specimen at a given temperature is nown, the specimen may be heated very rapidly to that mperature and the power input reduced to the appropriate lue when the specimen temperature will remain constant ith negligible "overshoot." For the same reasons the ecessary power input to the stage is small. The total power quired to maintain the zinc specimen described earlier at 0° C was less than 2 W, of which 0·8 W was produced by e electron bombardment and approximately 1 W was ssipated by the filament. To maintain a steel specimen × 3 × 1·5 mm at 1000° C a total power input of less than W was necessary.



Plan and sectional elevation of the hot stage

A vacuum of 10^{-5} mm of mercury or better can be easily aintained during the operation of the stage since only the ament and the specimen are hot. Outgassing of the filament uring operation is unimportant because of its high operating mperature and small dimensions. The principal source of s during operation is the specimen itself.

The stage has been used to study the martensite transformaon in 1·2% carbon steel. A sufficiently rapid quench to ppress pearlite formation was obtained by admitting ydrogen through a tube inserted in the glass cover plate. y adjusting the volume of gas admitted a specimen can be uenched to a predetermined temperature.

An important feature of this design is that, by a reduction specimen size, significantly higher specimen temperatures n be used for the same heat transfer to the objective. This follows from the fact that the specimen is the only significant source of heat, the amount of which is nearly proportional to the specimen area and the fourth power of the absolute temperature.

Polarized light observation requires that the window through which the specimen is observed should be as free from strain as possible. It was found that a hot setting cement could not be used to seal the window as the differential thermal expansion on cooling made the window nearly useless and consequently a cold setting cement had to be used. The window will deform elastically when the chamber is evacuated, but if the aperture is $\frac{3}{8}$ in. or less the window has very little influence on polarized light passing through it.

REFERENCES

(1) Oberhoffer, P. *Metallurgie*, **6**, p. 554 (1909).
(2) Rogers, B. A. *Metals and Alloys*, **2**, p. 9 (1931).
(3) Esser, H., and Cornelius, H. *Metals and Alloys*, **4**, p. 119 (1933).
(4) Chalmers, B., King, R., and Shuttleworth, R. *Proc. Roy. Soc. A*, **193**, p. 465 (1948).
(5) Nickols, D. G. *J. Iron Steel Inst.*, **160**, p. 415 (1948).
(6) Dewhurst, D. W., and Olney, M. J. *J. Iron Steel Inst.*, **169**, p. 221 (1951).
(7) Brinson, G., and Moore, A. J. W. *J. Inst. Metals*, **79**, p. 429 (1951).
(8) Maréchel, J. R., and Doucet, M. *Rev. Mét.*, **48**, p. 561 (1951).
(9) Mott, B. W., and Ford, S. D. *Research*, **6**, p. 396 (1953).
(10) Williams, A. L. *G.E. Research Laboratory Report*, R L 230 (June 1949).
(11) Cech, R. E. *Rev. Sci. Instrum.*, **21**, p. 747 (1950).

A superconducting reversing switch

By I. M. Templeton, M.A., D.Phil.,* Division of Physics, National Research Council, Ottawa, Canada

[*Paper received* 6 *January*, 1955]

A reversing switch is described in which either of two pairs of tantalum wire elements may be brought into the normal (resistive) state by energizing miniature electromagnetic circuits. Some measurements of small thermal electromotive forces are given in illustration of the performance of the switch.

The measurement of small voltages in a liquid helium bath is often seriously complicated by the existence of relatively large thermal voltages developed in the leads brought out to the measuring apparatus (e.g. potentiometer) at room temperature. A superconducting modulator has already been developed by the author(1) for measuring voltages lower than about 10^{-6}–10^{-7} V, but this is unnecessarily complicated for the higher ranges. For voltages of one microvolt and upwards, the required accuracy may readily be attained using conventional instruments if a reversing switch can be provided *in the liquid helium bath*, so that "spurious" e.m.f.'s may be eliminated.

Some attempts have been made in this laboratory to use mechanically operated switches, but it was found that the combined effects of condensation of air during cooling, loss of elasticity of the contact systems and trouble from contact potentials made it impossible to obtain a satisfactory and reliable on-off contact in this way.

THE PRINCIPLE OF THE SUPERCONDUCTING REVERSING SWITCH

A reversing switch may be considered satisfactory in operation if:

(1) any series resistance introduced is negligible in comparison with the input impedance of the measuring instrument;
(2) the output impedance of the source is small in comparison with any parallel resistance introduced by the switch itself;
(3) the series resistance of the switch is negligible in comparison with the parallel resistance.

In practice, most metallic sources of e.m.f. at helium temperatures will have internal resistances below $10^{-3}\,\Omega$, and condition (2) would therefore be satisfied with a parallel resistance as low as $1\,\Omega$. If such a parallel resistance is introduced, the series resistance must then be $10^{-3}\,\Omega$ or lower.

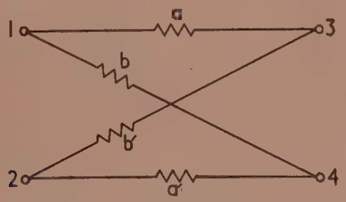


Fig. 1. Diagram of superconducting reversing switch

These conditions are satisfied with the system shown in Fig. 1. The resistances are small flat coils of tantalum wire, each having a resistance at 4·2° K *in the non-superconductin* *state* of about $2\,\Omega$. Coils *a*, *a′* are placed in between th poles of one small electromagnet and *b*, *b′* in another. magnetic field of suitable magnitude will reversibly destro superconductivity in a pure superconductor, so that if magne *B* is energized to give a field greater than approximatel 60 G on the tantalum coils, there will be direct (superconduc ing) connexion between terminals 1–3 and 2–4, with a resis tance between the lines of approximately $1\,\Omega$. Conversel if magnet *A* is energized, the direct connexions are 1–4 2–3. A switch based on this system has been constructed.

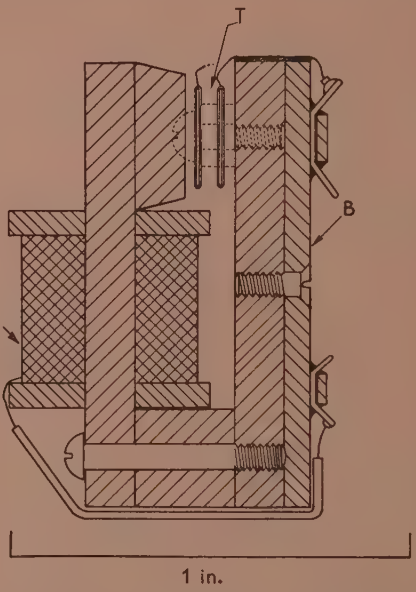


Fig. 2. Superconducting reversing switch

B, Bakelite terminal board; *T*, tantalum coils; *C*, electromagnet coil.

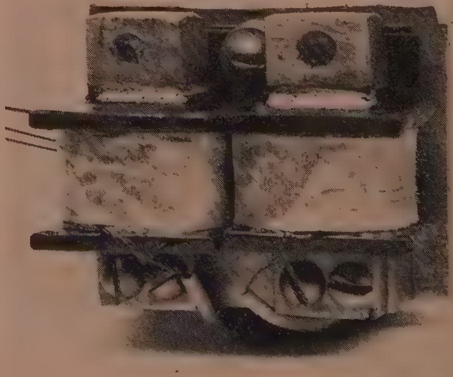


Fig. 3. Superconducting reversing switch

---

* National Research Laboratories Postdoctorate Fellow. Now at British Thomson-Houston Co. Ltd., Rugby.

CONSTRUCTION AND OPERATION

The coils consist of fifty turns each of insulated 0·002 in. ntalum wire, wound on two 5 mm strips of thin Bakelite. he length of the winding in each coil is approximately mm and the spacing between coil centres about 1·5 cm. he two strips of Bakelite are mounted in the twin magnet stem shown in Figs. 2 and 3 such that two coils lie in ch air-gap.

The field-windings on the armature are each of approxi- ately 1000 turns of 0·004 in. enamelled copper wire. Each inding has a resistance at 4·2° K of approximately 1 Ω, nd a current of approximately 20 mA is required to produce itical field in the gap. Thus with a working current of) mA, the power dissipated is approximately 1·5 mW.

Terminals are small strips of copper bonded with Araldite) a terminal board on the back of the steel baseplate.

APPLICATION TO THE MEASUREMENT OF THERMAL ELECTROMOTIVE FORCES

The reversing switch has been used for various measure- ents of thermoelectric force which will be described in etail elsewhere. Fig. 4 shows some results obtained from series of measurements of the thermoelectric force of a otassium–lead thermocouple, the "cold" junction being nmersed in liquid helium at 4·2° K. It will be seen that otential measurements can be made to an accuracy of 0·01 μV, which is approaching the limiting noise figure of the galvanometer amplifier(2) used as the measuring instrument. Thermal electromotive forces on the leads were of the order of 0·5 μV.

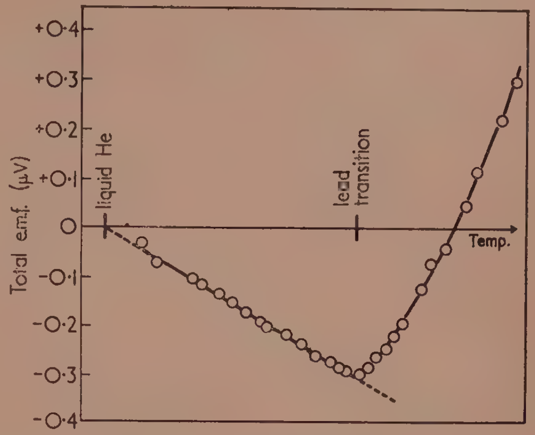


Fig. 4. Total e.m.f. of potassium *versus* lead showing lead transition

REFERENCES

(1) Templeton, I. M. To be published (1955).

(2) MacDonald, D. K. C. *J. Sci. Instrum.*, **24**, p. 232 (1947).

A tilting micromanometer with continuous sensitivity control

By L. R. Taylor, Department of Entomology, Rothamsted Experimental Station, Harpenden, Herts

[*Paper first received* 6 *October*, 1954, *and in final form* 14 *January*, 1955]

A null-reading liquid manometer is described in which the meniscus is returned to the reading position by varying the angle of slope. Sensitivity automatically decreases as the applied pressure increases; it is highest at zero readings and its absolute level can be continuously varied. A magnification factor can be employed by using different reading positions on the tube which is 0·1 in. bore, pivoted near the reservoir and tilted at its distal end by a standard micrometer-head, so keeping the construction simple and not critical. The prototype, which is wall-mounted, reads easily at air-speeds of 7·5 ft/s with a Pitot-static tube; the highest limits of accuracy assessed are ±0·2 dyn/cm², i.e. 6·5 ft/s ± 0·5%. The upper reading limit is about 0·7 in. w.g. (50 ft/s).

he standard tilting-pattern manometer with two glass servoirs and a steel frame,(1) is rather complicated. With pressures down to 0·02 in. w.g. (10 ft/s) can be read with asonable accuracy, but for pressures below this the Chattock uge(2) is in general use. This is expensive and, being a boratory instrument requiring bench-space, may be incon- nient if used only occasionally. Wide bore inclined-tube anometers(3) are not conveniently read from above and quire specially made micrometers. A wall-fixing, null- ading manometer has therefore been made with a narrow re inclined tube, in which the meniscus is returned to zero varying the angle of inclination, instead of raising or wering the reservoir as in the type used by Preston.(4) A agnification factor can thus be used to reduce the minimum easuring division, by a factor of up to ×0·1 in the present strument, by reading at different graduations on the tube. The sensitivity is continuously variable with the angle of inclination and can be increased almost indefinitely by reducing the angle to small or negative values. This is accomplished in the normal reading procedure; the sensitivity is highest at the zero value and automatically decreases with increase in pressure reading and increase in magnification.

The prototype, which was inexpensive and is of simple construction, reads from 0·01 to 0·7 in. w.g. within ±1% limits (6·6 to 50 ft/s ± 0·5%), but it seems likely that it could be developed to read lower pressures if required.

The instrument consists of a cylindrical reservoir connected by a coil of flexible tubing to a graduated glass tube held against a heavy strip of metal, pivoted at one end and supported at a known distance from the pivot by the tip of a micrometer-head mounted vertically. The pivot and micrometer-head are mounted on a metal backboard which is, in turn, mounted on a wooden baseboard screwed to the wall when in use (Fig. 1).

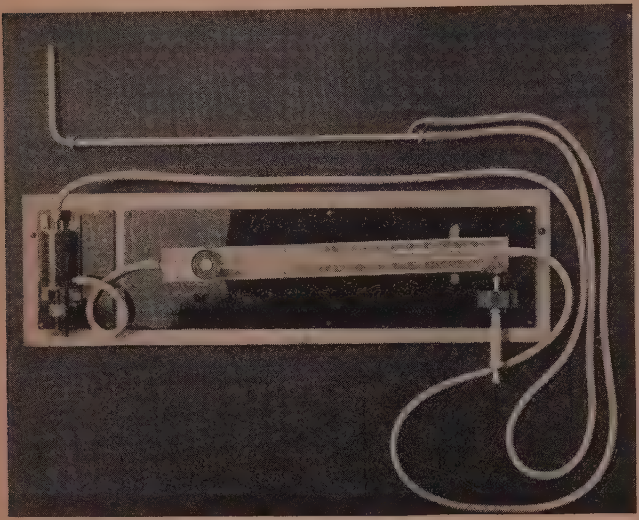


Fig. 1. Inclined-tube-manometer fitted to a standard Pitot-static tube

DETAILED DESCRIPTION

The reservoir *A* (Fig. 2) is made from 2½ in. long × 1¼ in. internal diameter brass tubing, plugged at the ends with brass disks and with a ¼ in. diameter inlet and outlet tube in the top and at the bottom of one side respectively. It is mounted on a flat brass plate, *B*, 2½ in. × 1¼ in. × 3/32 in. which slides in grooves *C* fixed to a Duralumin baseplate, and it is supported on the tip of a screw *D* to provide rough adjustment of the liquid level in the reservoir, and hence of the meniscus in the sloping tube.

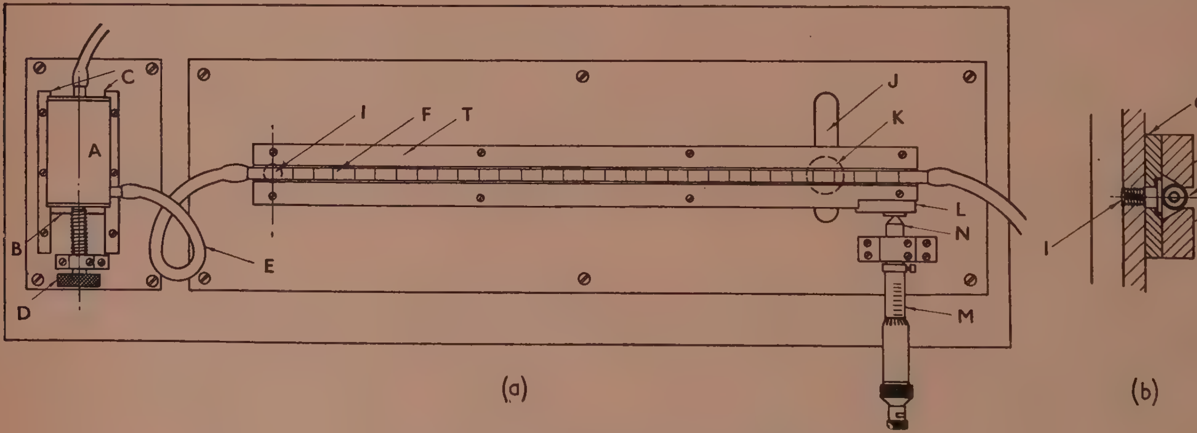
The outlet is connected to the graduated glass tube by flexible tubing *E*, made of rubber in the prototype and coiled in a single loop, so that the glass tube may be tilted without undue distortion of the rubber. Though the amount of movement is small a straight connexion, as shown in the Krell pattern,[(3)] constricts visibly as the glass tube is raised.

The glass tube *F* is 1/10 in. bore × 16 in. long and graduated for 15 in. in 1/20 in. divisions, with a total error of −0·5 mm in 15 in. The thirty ½ in. graduations are numbered ar continue right round the glass. Straightness of bore is least as important as regularity of cross-section, but neith are highly critical if the instrument is calibrated against standard. The tube in use was specially made yet very chea

This tube is held against a heavy brass strip *G* by tw transparent Perspex flanges *T* forming a clamp which allow light to reflect from behind the tube on to the graduation but grips the tube firmly. The brass strip is 1½ in. × 3/16 i and 16 in. long and is pivoted at one end on a cylindric bearing *I* screwed into the aluminium backboard. The zer point of the glass scale overlies the marked centre of th bearing [see Fig. 2(*b*)]. At a distance of 13½ in. along th brass strip is a peg with a flanged head *K* which slides within recessed slot *J* and prevents the tube from falling forwar At a point exactly 15 in. from the pivot a piece of steel let into the brass strip is supported on the micrometer-head *M* the square end of which is covered by a tapered cap with th tip slightly rounded *N*. The weight of the brass strip hold it on to this cap as the micrometer-head is screwed up down.

As the micrometer is elevated the tip slides against th steel inlay, but the movement is very slight and the effe upon the geometry of the instrument is negligible. Fo instance, the maximum elevation of 0·9 in. produces th maximum error which is 0·2% of the micrometer readin i.e. 0·02% of the pressure at high magnification.

The main requirements in the instrument are that th spacing of the pivot and micrometer should be accurate known; that the 0 graduation mark should coincide with th pivot centre; that the micrometer should be vertical the horizontal position of the graduated tube and that th reservoir and particularly the tube plate *G* should be suff ciently heavy and smoothly pivoted, since they are gravi returned. Absolute ethyl alcohol is used as the manometr liquid and use of the instrument would be facilitated separate filling and drain holes in the reservoir. When th manometer is firmly mounted, the level position of the tub can be ascertained by removing the rubber connexio inserting a small bubble of alcohol and manipulating th micrometer to bring the bubble to a halt at the require graduation.



(a) (b)

Fig. 2. Plan and section of manometer

READING PROCEDURE

The value of magnified readings is based upon simil triangles, graduation 30 on the glass tube traversing 10 tim e vertical distance of graduation 3 when the micrometer is vated and hence a magnification of ×10 is obtained for adings taken with the meniscus at graduation 3. This sition can only be used for pressures below $\frac{1}{10} \times 0{\cdot}9$ in. alcohol (maximum elevation), and if graduations 0, 3 d 30 are in a perfectly straight line. This depends upon e straightness of bore of the tube and in fact the tube now use is not quite straight, only graduations 3 and 15 being linear with 0 and 30. However, they give adequate coverage the range and intermediate positions have not been found cessary. A rough measure of the pressure is taken at aduation 30 and if it is below 0·09 in. of alcohol, position 3 ay be used. If it is between 0·09 in. and 0·45 in. position may be used, and if above 0·45 in., position 30.

The meniscus is adjusted to slightly above the chosen sition by the reservoir screw and returned accurately by ising the micrometer with the pressure off. The resulting ght tilt of the tube (about 0·25°) facilitates adjustment by ducing sensitivity; a ×10 microscope eyepiece is used to ad the meniscus. The micrometer is then read, the pressure rned on, and the micrometer raised to bring the meniscus ck to the same graduation. A second micrometer reading taken and the difference, divided by the magnification ctor of the position used and multiplied by the specific avity of the manometric liquid gives the pressure in inches ater gauge. The micrometer-head, which is a stock com- ercial instrument, is graduated in 1/1000 in. from which 10 000 in. can be estimated, or it can be obtained with 10 000 in. graduations.

CALIBRATION

The conversion of readings to pressure involves the specific avity of the liquid and the geometry of the instrument. ith absolute alcohol the usual precautions are necessary to event change of specific gravity by water uptake;⁽⁴⁾ the use *n*-octane obviates this risk, but raises other problems dis- ssed later. A brief consideration of the geometry shows at tangential displacement of the tube axis from the pivot ntre of up to 0·05 in., and displacement of the micrometer is from the vertical of up to 1° will not produce measurable rors. However, if the bore of the tube is out of line by 01 in. at the reading graduation, or if the tube zero is splaced axially from the pivot centre by 0·01 in., errors of e order of 0·00025 in. appear with readings at a magnifi- tion of ×10. It is therefore important that the tube should held firmly in the Perspex clamp, and its position relative the pivot centre made clearly visible without removing the be.

Calibration of the present instrument, from 0·03 to 0·64 in. g., against a standard 13 in. Chattock gauge gave a recti- ear relation with $\tan\phi = 1{\cdot}95$ at graduation 15 and 0·98 graduation 30, where $\tan\phi$ = true magnification (Fig. 3). e expected values M are consistently high at $+2{\cdot}5$ and 2·0% respectively so that calibration consists of making a nple proportional correction over the whole range for each ading position, i.e. correcting M. Zeros were obtained an inclination of 0°23′ and on this occasion the meniscus s too active at the "on" readings to obtain a reliable libration at position 3, i.e. the sensitivity was too high for a agnification of ×10 to be used with the system concerned.

The readings were compared by dripping water into an tight flask connected to the system; the two manometers re in parallel. It seems probable that temperature changes re the cause of the fluctuations in pressure; these were not ident with the system open, i.e. at zeros, and therefore are not likely to have been effective within the manometer itself. The effect of cold water entering such a closed system is, however, considerable and was examined in detail by Preston⁽⁴⁾ who surmounted the difficulty by using a system connected to the atmosphere only through a water buffer, by which the temperature fluctuations were almost eliminated. This was impracticable in the present circumstances when the main object was straightforward calibration.

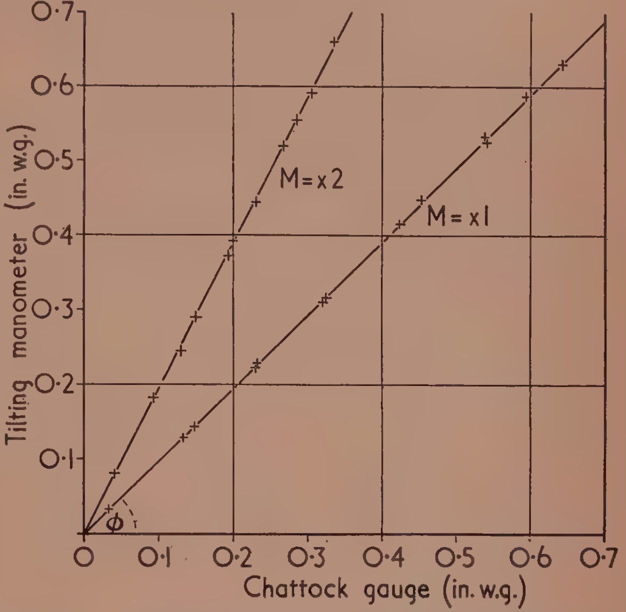


Fig. 3. Calibration curve at expected magnifications of ×1 and ×2 against a standard 13 in. Chattock gauge

SENSITIVITY

The sensitivity is considered as dI/dQ where I is the index of movement (the meniscus) and Q is the quantity measured (pressure). It is given by MacMillan⁽⁵⁾ as:

$$\left(\frac{a}{A} + \sin\theta\right)^{-1} \tag{1}$$

where a = the cross-sectional area of the inclined tube,
A = the cross-sectional area of the reservoir,
θ = the angle of inclination of the tube.

When a geometrical magnification is used, the sensitivity at a given pressure is *reduced*; for $\theta \propto M$ where M is the magnification factor. The magnification applies only to the scale of measurement, i.e. the smallest reading is equal to the smallest micrometer division $\times 1/M$.

It may be necessary to reduce sensitivity by setting to zero with θ positive if the pressure is not steady. By raising the reservoir and increasing θ with the pressure on, an inclination can be selected at which the sensitivity is just sufficiently low to be unresponsive to small pressure fluctuations. The sensitivity, which can be further increased by making θ negative, is 150 with $\theta = 0°$; 100 with $\theta = 0°12'$, and is at a minimum of 15 with $\theta = 3°30'$ (maximum elevation). In most of the work for which the manometer was made and for which it has been used, zero settings have been obtained with $\theta \simeq 0°20'$, and air-speeds of 7–10 ft/s have been read without difficulty arising from undue sensitivity.

THE ACCURACY OF THE PROTOTYPE

The practical limits of accuracy are determined by the stability of the zeros and the minimum observable movement of the meniscus at zeros and at readings. Zero stability depends mainly upon differential temperature effects on the liquid, its containers and on the surface tension, and upon evaporation of the liquid; with a wall-fixing instrument, errors caused by tilting the base can be neglected.

Temperature effects cannot be eliminated with the present model, as suggested by MacMillan,⁽⁵⁾ because the amount of liquid required by the equation:

$$Vr/A = 0{\cdot}145\ \text{cm}^2 \qquad (2)$$

where V = the volume of liquid and r = the radius of the tube, is 0·55 in.³ which is insufficient to fill the rubber coil. As a result the zero drifts irregularly. This is shown in Fig. 4 by zero readings which were taken from actual records made in a greenhouse and have been selected to illustrate major changes in drift not likely to occur in the laboratory. However, by taking zero readings as frequently as is found necessary for the level of accuracy required, the general trend can be found, intermediate zeros interpolated and the large effect eliminated as in normal procedure. This also largely removes evaporation effects, which are fairly regular.

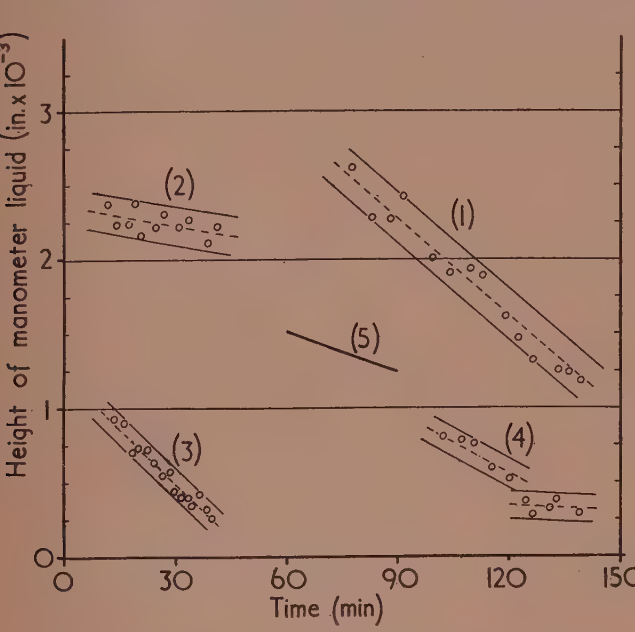


Fig. 4. Drift and scatter of zero readings (in. alcohol) on a time base (min). Four sets of data for various conditions in a greenhouse:

(1) 21 August 10·42–11·44 h, temperature 23·3–23·9–23·7° C.
(2) 22 August 13·11–13·41 h, temperature 29·5–29·7–29·3–29·4° C.
(3) 21 August 18·33–18·59 h, temperature 22·7–21·7° C.
(4) 20 August 19·52–20·29 h, temperature 18·2–17·1° C.
The parallel lines are the regressions and 5% fiducial limits.
(5) Zero drift caused by evaporation of n-hexane at θ = 1°

The minimum observable movement is included, in practice, in the residual scatter of points about the mean zero line which, in Fig. 4, is the regression line assumed for convenience to bear a linear relationship to time. Also included are minor temperature and evaporation fluctuations and defects in the micrometer screw, for although meniscu movement may be visible with high optical magnification it may not be possible to record it accurately. No attemp was made to return the meniscus from a particular direction It was returned roughly to the required position as th pressure was turned off, left for a moment to become stead and then "tuned" to the graduation mark with the right ey close to the microscope eyepiece. With the head in thi position the micrometer is out of the field of vision (see Fig. 1) it is therefore unlikely that a personal bias towards th expected reading could influence the results without a con scious effort to control the number of micrometer turns b touch.

There is no reason to suppose that the factors involved i the scatter when the pressure is on differ from those whe the pressure is off, except in relation to actual pressur fluctuations for which the manometer is not responsibl and to sensitivity which changes with θ (time-lag is no considered here).

If the zero is obtained with $\theta = 0°17'$, (micrometer a 0·07 in.; sensitivity 90), the inclination at 0·0128 in. w.g (7·5 ft/s) will be $\theta = 1°9'$ (micrometer 0·24 in.; sensitivity 40). The four sets of zeros shown in Table 1 were obtained a sensitivities of a similar range, i.e. 45, 57 and 77, taken fro actual records in which readings of about 0·0125 in. w.g were taken after each zero using a magnification factor of ×1 In Table 2, the scatters of these zeros are given as standar deviations compared with sensitivity. It is evident, from th standard deviations in Table 2, that differences of sensitivit of this order did not appreciably affect the readings withi the range considered and that other factors had a greate effect. As this is so, the errors of this instrument may b assessed from the scatter of these zeros about the mea With this kind of reading there will inevitably be a larg number of small errors which can only be treated as a statistical population and for this purpose the limits of accurac are those within which 95% of the population of points wi fall, i.e. the mean ±1·96 σ where σ is the standard deviatio about the regression. Thus a 95% accuracy is equal t 2 × 1·96 σ.

Table 1.—*Change of zero settings with time*

Run 1		*Run 2*		*Run 3*		*Run 4*	
T	*M*	*T*	*M*	*T*	*M*	*T*	*M*
0	0·0	0	0·0	0	0·0	0	0·0
6	−3·4	3	−1·4	3	−0·8	5	−0·3
4	+0·1	3	0·0	2	−2·0	3	−0·2
4	+1·4	3	−0·7	2	+0·3	5	−1·4
8	−4·0	4	+0·4	2	+0·1	5	+0·1
5	−1·1	2	+1·1	2	−0·9	4	−1·7
5	+0·3	4	−0·9	2	−0·9	2	−0·8
3	−0·4	3	+0·5	2	+0·2	5	+0·7
6	−2·8	5	−1·5	1	−1·4	2	+0·3
3	−1·4	3	+1·2	2	−0·3	6	−0·9
4	−1·6			2	−0·1		
7	−0·6			1	−0·4		
3	−0·2			2	+0·6		
4	−0·5			2	−1·0		
				1	−0·6		

T = Time interval between readings in minutes.
M = Difference between successive micrometer settings in thousandths of an inch.

The micrometer is read twice for each pressure measur ment; at zero and at "on"; both of these readings will have standard deviation (σ_z and σ_0) which is a measure of th

Table 2. *Zero scatter compared with sensitivity*

	Average micrometer elevation (in.)	*Angle of inclination* (θ)	*Sensitivity* $(a/A + \sin\theta)^{-1}$	*Standard deviation* ($\sigma_z \times 10^{-4}$ in.)	*95% limits* ($\pm 1{\cdot}96\,\sigma_z \times 10^{-4}$ in.)	*Number of observations n*
Run 1	0·1558	0°30′	57	9·1	±17·8	14
Run 2	0·0912	0°23′	77	7·1	±13·9	10
Run 3	0·1556	0°31′	57	4·8	± 9·4	15
Run 4 (1)	0·2315	0°55′	45	4·0	± 7·8	5
(2)				5·1	± 9·9	5

controllable errors in the instrument. Because of the
gnification factor, the standard deviation of the required
essure (σ_P) is $\frac{1}{10}$ of the standard deviation of the difference
the micrometer readings (σ_D), i.e.

$$\sigma_P = \tfrac{1}{10}\,\sigma_D = \tfrac{1}{10}\sqrt{(\sigma_z^2 + \sigma_0^2)} \qquad (3)$$

there is no evident correlation between sensitivity and σ
er this range, equation (3) can be reduced to

$$\sigma_P = \tfrac{1}{10}\sqrt{2\sigma_A^2} \qquad (4)$$

ere σ_A^2 is the variance of any of the available sets of zeros,
a weighted average. Such an average, using all the data,
cluding the wide deviation at the beginning of run 1, gives
e general level of the limits of accuracy in uncontrolled
nditions as $\pm 14{\cdot}84 \times 10^{-5}$ in. w.g.

In better conditions this is improved upon. Apart from
e two sections of run 4 in which the data are rather limited,
e most consistent results are in run 3. Using these in
uation (4) the maximum accuracy of the instrument in its
esent form, may be obtained, i.e. $\sigma_P = 6{\cdot}86 \times 10^{-5}$ in.
cohol, which gives 95% of readings within $\pm 10{\cdot}6 \times$
$^{-5}$ in. w.g. This is a 95% accuracy of 0·4 dyn/cm^2
0·2 limits) which means that airspeeds of 6·6 ft/s may
measured to within ±0·5% if a sufficiently accurate
tot-static tube is available.

POSSIBLE LIMITS OF ACCURACY

Preston used a similar instrument in which the meniscus
s returned to zero by raising the reservoir, instead of
creasing θ. The sensitivity was therefore the same at zeros
at readings; sensitivity control was less flexible than with
e present instrument and no magnification was available.
acMillan(5) treated this type of instrument theoretically
d gave the expected accuracy as $7{\cdot}9 \times 10^{-5}$ in. w.g.
5% limits of $\pm 2{\cdot}41 \times 10^{-5}$ in. where the theoretical
curacy is taken to be equal to the 99·8% limits). He
inted out that sensitivity is not the immediate problem in
ducing this limit and indicated the micrometer screw,
ing the base and evaporation as sources of error when the
nperature effect is eliminated. Preston's results confirm
s, for he reported a "sensitivity of better than" $19{\cdot}75 \times$
$^{-5}$ in., but could only measure to $39{\cdot}5 \times 10^{-5}$ in.(4)
ver(6) obtained an accuracy of $0{\cdot}5 \times 10^{-5}$ in. using a
rrow bore two-cup manometer with a high degree of
nperature control and a magnification of ×10. Further,
crometer-heads calibrated directly to 10×10^{-4} in., and
ding to 1×10^{-5} in. by vernier are available. The magni-
ation of the present type of instrument could be increased
×50 without making the tube too long; using the accurate
crometer mentioned above, 5×10^{-7} in. could then be
asured, so that accuracy of measurement need not be a
niting factor. To do this the tube should be 0·5 m long,
ding at 1·0 cm; it should be extended 4 to 5 cm below
e pivot so that the meniscus is well away from the flexible
nt.

Tilting of the base is no problem with a wall-fixing instrument; temperature control by MacMillan's method [equation (1)] could be obtained only by decreasing the tube bore, although increasing the reservoir diameter also contributes towards satisfying the equation. Using alcohol in an insulated reservoir 5 cm square and a tube 1 mm in diameter a high degree of temperature control should be obtained.

The ultimate limit of response is determined by the meniscus resistance which may be important with tubes of 1 mm diameter. The use of *iso*- or *n*-octane or *n*-hexane, which, in a tube of this diameter(7) has a Jamin-resistance of about a tenth that of alcohol in a tube 1·8 mm diameter,(8) reduces this limit considerably and a better meniscus is formed. But leakage from the surface may be expected to prevent the use of extremely high sensitivities, if these have any value. However, indices of *n*-hexane in a 1 mm tube and alcohol in a 0·1 in. tube, horizontal and open at one end to atmosphere, diminish at about the same rate, i.e. 0·1–0·2 mm/h, and a meniscus of *n*-hexane recedes at about 0·017 in./h in the present instrument (Fig. 4, Part 5). Thus there would be little more leakage with *n*-hexane than with alcohol, nor could evaporation be a much greater problem; even less so with *n*-octane and at higher sensitivities, for drift is proportional to tan θ. Also specific gravity is constant and lower than with alcohol, hence a higher magnification factor is obtained. Provided the coiled rubber connector is replaced by polyvinylchloride, *n*-octane or *n*-hexane could be used; with a wider reservoir, narrower tube and more accurate micrometer, the degree of accuracy would then depend almost entirely upon the temperature control achieved.

ACKNOWLEDGEMENTS

I would like to thank Mr. A. E. Hall of Rothamsted Experimental Station for making and Dr. W. S. Coleman of Blackburn and General Aircraft Co., for calibrating the instrument, Dr. C. G. Johnson of Rothamsted Experimental Station for reading the manuscript and Mr. C. Salter of the National Physical Laboratory for a very helpful discussion.

REFERENCES

(1) Ower, E. *The measurement of air flow*. 3rd Ed. (London: Chapman and Hall, 1949).

(2) Pannell, J. R. *Engineering* [*London*], **96**, p. 343 (1913).

(3) Hunsaker, J. C., Buckingham, E., Rossell, H. E., Douglas, D. W., Brand, C. L., and Wilson, E. B. *Smithsonian Misc. Collect.*, **62**, p. 34 (1916).

(4) Preston, J. H. *Engineering* [*London*], **172**, p. 645 (1951).

(5) MacMillan, F. A. *J. Sci. Instrum.*, **31**, p. 17 (1954).

(6) Ower, E. *Aeronautical Research Council Reports and Memoranda*, No. 1308 (London: H.M. Stationery Office, 1930).

(7) Bielak, E. B., Calderwood, G. F. N., and Mardles, E. W. J., *Nature* [*London*], **174**, p. 1009 (1954).

(8) Calderwood, G. F. N., Douglas, H. W., and Mardles, E. W. J., *Analyt. Chem.*, **25**, p. 935 (1953).

An automatic monitor for measuring tritium contamination in air

By D. F. Shaw, M.A., D.Phil., Clarendon Laboratory, University of Oxford

[*Paper first received* 11 *February, and in final form* 1 *March*, 1955]

This paper describes the design and principle of operation of an automatic monitor for testing air for contamination by tritium. The method of detection is based on the measurement of ionization in an air sample. A direct-reading meter registers the level of radioactivity and provision is made for operating a recorder. The instrument was developed to test for tritium contamination but may be used to detect other airborne radioactive gases, e.g. $^{14}CO_2$ or radon.

Tritium, the isotope of hydrogen of mass 3, is a radioactive β-emitter with a half life of 12·5 years (1, 2) and a maximum β-energy of 18·5 keV.(3, 8) If air containing tritium is inhaled it is assumed that the tritium will exchange with hydrogen in the water molecules in the lungs.(4) Some of the tritium thus deposited in the body will decay and the emitted β-particle, which has a maximum range in tissue of about 7 μ, will produce local ionization. It has been estimated(5) that 10 mc of tritium deposited in the body of a standard man of 70 kg weight will produce ionization equivalent to that due to γ-ray exposure at the maximum permissible level. Also, assuming complete absorption in the lungs and a mean biological life of ten days the maximum permissible concentration in air for continuous inhalation is about 5×10^{-5} μc/cm^3.

The need for an automatic monitor is shown by recent experiments which have been performed in this laboratory(6) to investigate the reaction products of collisions between accelerated deuterons and tritons. The target used was a gaseous mixture of tritium and hydrogen. The deuteron beam entered the target chamber through an open canal. Inevitably, some of the target gas diffused through this canal into the accelerator tube. The rate of diffusion was reduced considerably by circulating the gas in a closed system. With this arrangement about 50 mc of tritium escaped into the accelerator tube per hour. This passed through the main pumping system and was collected in a storage bottle. The target was replenished by introducing more gas through a heated palladium leak. Every reasonable precaution was taken to prevent the escape of tritium into the laboratory but there was always the risk that a dangerous quantity would be released in the event of a leak in the vacuum system. The monitor was operated during the experimental runs sampling air in the vicinity of the target assembly and pumping system. Occasionally a significant activity was registered, but in all cases this was less than 10% of the recommended maximum permissible level.

The specific activity of the target gas used in these experiments was determined using a Geiger counter. It was decided not to use this method for air monitoring because of difficulties likely to be encountered owing to the presence of oxygen and water vapour in the gas filling. The latter could be removed in a trap but it is conceivable that some of the tritium would be removed also following exchange with hydrogen. Instead an ionization chamber was chosen as the most suitable basis for the monitor.

PRINCIPLE OF OPERATION

The monitor is shown schematically in Fig. 1. A reciprocating pump driven by a synchronous motor fills with a sample of air as the piston moves downwards and on the return stroke this sample is passed into the ionization chamber I_1. The pump operates at one cycle per minute, the upwar and downward strokes of the piston occurring at the sam speed. Chamber I_2, identical in construction with I_1, i filled with uncontaminated air at atmospheric pressure. Th ionization chambers operate on the condenser principl Normally the collecting electrodes are connected through th contacts of the switch S_1 to a fixed potential. They are als permanently connected one each to the control grids of double-tetrode electrometer valve which feeds into the differential direct-coupled amplifier. When the piston starts downward stroke and I_1 has just been filled with a sample o air, S_1 is energized and I_1 and I_2 thus isolated from th

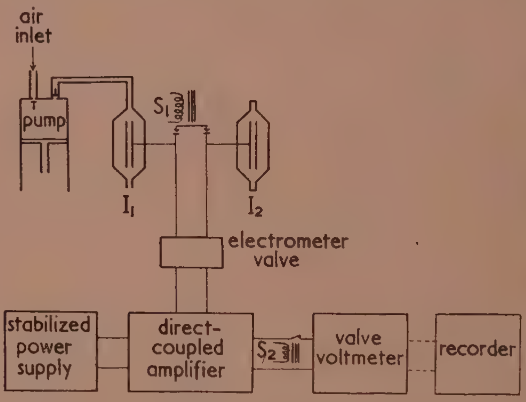


Fig. 1. Schematic diagram of monitor

charging potential. S_1 is controlled by switches operated b the piston rod so designed that they close only when the latte is moving downwards. I_1 and I_2 remain isolated for 25 in each cycle and during this period any ionization occurrin in the air filling will result in a corresponding fall in collecto potential. The output voltage of the amplifier will, however depend on the difference between the charge collected in I and that in I_2; thus the effect of ionization due to cosmic an other background radiations is eliminated. At the end o each integration period switch S_2 closes momentarily and th amplifier output voltage is registered on the valve voltmeter This signal is stored until the next cycle.

IONIZATION CHAMBERS

The design of the ionization chambers is shown in Fig. 2 The body A is a cylindrical brass tube 30 cm long, 14 cn diameter and 1·5 mm wall thickness with cone-shaped ends The volume is approximately 5 l. The centre electrode B which is a brass tube 30 cm long by 2·5 cm diameter, i mounted on a distrene insulating disk C. This insulator i coated with a thin layer of ceresin wax to prevent moistur ondensation and is protected by a dust cover *D*. The entre electrode has several 5 mm diameter holes drilled adially to reduce its weight to a minimum. All the interior dges are rounded off to prevent high local electric fields. he ends of the chamber are shaped to prevent stationary ockets when air is pumped through, thus ensuring complete ushing on each stroke and the removal of any activity resent in the previous sample. Before assembly the metal arts of the chamber were cleaned in chromic acid.

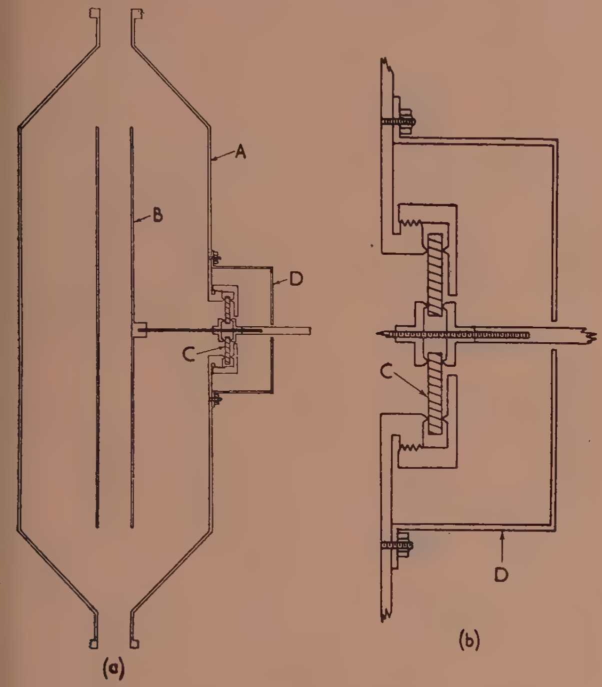


Fig. 2. Construction of ionization chamber

(*a*) Section of chamber.
(*b*) Insulator assembly (×3).

When the chamber is filled with air containing the maximum ermissible level of tritium the total tritium content of the ling is about 0·25 μc. A measurement of ionization rrent *versus* collecting voltage with a sample of 0·5 μc in e chamber gave saturation at about 9 V. The activity, 5 μc, was calculated from the saturation ionization current. practice a collector potential of 18 V is used.

When the ionization chambers are isolated the system is ry sensitive to electrical disturbances. A Tesla coil erated in the same room causes a complete discharge and e spark obtained from shorting the terminals of a high nsion battery reduces the collector potential by 1 or 2 V. avoid errors due to this, the coils of the electromagnetic lays S_1 and S_2 form respectively the anode loads of a double ode valve, and control is effected by changing the appro-iate grid bias.

DIRECT-COUPLED AMPLIFIER

The function of the direct-coupled amplifier is shown in g. 3. The main amplifier is based on the design reported Peirson(7) and was chosen because it was found particularly itable for differential amplification with both halves of the out electrometer operated dynamically.

The electrometer valve V_1, type DBM8A (by Ferranti Ltd.) was selected to have as nearly as possible identical i_a–v_g characteristics for the two halves. The filament is operated at a current of about 100 mA and the anode and screen supply voltages are 6 and 4·5 V respectively. Although operation of the valve at this lower rating reduces the mutual conductance to a third of the normal value, differences between the characteristics of the two halves are reduced appreciably and the grid current of the second half, which would normally be operated at a fixed grid potential, is reduced to a fairly low value. Under the selected conditions with the cathode potential 7 V negative with respect to the negative end of the heater, the combined grid and leakage current with the ionization chambers connected is less than $1\cdot5 \times 10^{-14}$ A for each half over the operating range of grid potential.

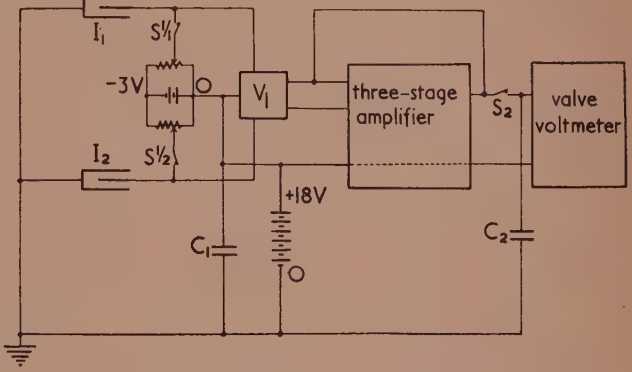


Fig. 3. Direct-coupled amplifier

Negative feedback is applied to the first anode of V_1 instead of the second control grid. This modification is necessary since the input resistance of each half of V_1 must exceed $10^{14}\,\Omega$ to avoid undue leakage across I_1 and I_2.

The collecting potential on each ionization chamber is applied between the appropriate control grid of V_1 and earth. The operating bias for V_1 is obtained without the necessity for a large cathode biasing resistance by returning the cathodes of V_1 and the subsequent stages to a line at 18 V positive to earth, this being the potential across C_1. By changing the potential across this condenser the collecting voltage on the ionization chambers can be altered without disturbing the balance of the amplifier or changing the bias on V_1. Under the chosen operating conditions the static grid potential of each half of V_1 is slightly positive with respect to cathode and therefore it is convenient to balance the amplifier with both grids at cathode potential. The potentiometers are incorporated for calibration purposes and to enable a periodic check to be made on the overall gain of the amplifier. The latter may be varied by changing the percentage of negative feedback. Under normal conditions the maximum output signal from the three-stage amplifier is 2 V.

The valve voltmeter consists of a type E1423 electrometer (by Mullard Ltd.) followed by a balanced bridge amplifier. The output voltage is registered on a moving coil meter connected between the two anodes of the last stage. C_2 is a length of Uniradio 39 coaxial cable of total capacity 100 pf. The outer conductor of this cable is cut away at each end a distance of 1 in. and the polystyrene insulator cleaned thoroughly so that the leakage of charge is small compared with the grid current of the electrometer valve. The latter is about 10^{-14} A. Hence, when S_2 is open the potential of this electrometer control grid rises at the rate of about 10 mV/min. This therefore provides a satisfactory means of registering the amplifier output at the end of the preceding cycle while the next measurement is being made.

At maximum sensitivity a full scale deflexion on the valve voltmeter corresponds to an ionization current of 3×10^{-13} A and a tritium level of 5×10^{-5} μc/cm^3, i.e. the maximum permissible for continuous inhalation. A current of 3×10^{-14} A can be detected with certainty.

CALIBRATION

One of the advantages of this type of monitor compared with a continuous flow method is that a direct calibration can be made with tritium. This has been done using a mixture of hydrogen and tritium which was analysed in a mass spectrometer at the Atomic Energy Research Establishment. The original sample contained about 100 mc of tritium and the small amount required for the calibration was obtained by expanding this into a large evacuated volume to which was connected a 10 cm^3 sampling bottle. The pressure in the system after the expansion was measured with a McLeod gauge. The sample collected in this way was $5{\cdot}4$ μc.

Three independent calibrations were made and in each case the indicated activity was less than calculated, by a factor between two and three. Unfortunately, these measurements could not be carried out until eight months after the gas mixture had been analysed and in the meantime it was stored in a bottle sealed with a rubber tap. It is believed that the discrepancy was due to the loss of tritium by exchange with hydrogen, either in the rubber or in water vapour which was subsequently condensed in the liquid air trap on the McLeod gauge. It is hoped to test this hypothesis by carrying out an independent analysis of the remaining gas. However, these measurements show that a semi-empirical calibration is sufficiently accurate for the monitor to be used for radiation protection.

MEMORY EFFECT

After the first sample had been measured the chamber was thoroughly flushed with uncontaminated air and then sealed. Subsequently there was a gradual build-up of ionization in the chamber to about 3% of the original value after 4 h. The ionization then remained constant for the next 24 h. This ionization was removed by flushing out the chamber with air a second time and there was no further build up afterwards. Most probably this effect was caused by tritium coming off the wall of the ionization chamber.

A previous attempt to detect a memory effect with a sample of $0{\cdot}5$ μc activity had given a negative result, probably because the resulting ionization current of 10^{-14} A would be hardly detectable with this apparatus.

ACKNOWLEDGEMENTS

The author is grateful to the Director of the Atomic Energy Research Establishment for the supply of tritium and for arranging its analysis by mass spectrometer. He also wishes to thank Professor Lord Cherwell for the facilities extended to him in the Clarendon Laboratory, and Mr. C. H. Collie for his encouragement and advice.

REFERENCES

(1) Novick, A. *Phys. Rev.*, **72**, p. 972 (1947).

(2) Jenks, G. H., Ghormley, J. A., and Sweeton, F. H *Phys. Rev.*, **75**, p. 701 (1949).

(3) Curran, S. C., Angus, J., and Cockroft, A. L. *Phys Rev.*, **76**, p. 853 (1949).

(4) Black, J. F., and Taylor, H. S. *J. Chem. Phys.*, **11** p. 395 (1943).

(5) Recommendations of International Commission on Radiological Protection, *Brit. J. Radiol.*, **24**, p. 46 (1951).

(6) Jarvis, R. G., and Roaf, D. *Proc. Roy. Soc., A*, **218** p. 432 (1953).

(7) Peirson, D. H. *Electronic Engng*, **22**, p. 48 (1950).

(8) Yerzaux, P. *J. Phys. Radium*, **13**, p. 94 (1952).

Apparatus for the measurement of the lifetime of phosphorescence phenomena

By A. van Roggen, Drs. Phys. Chem.,* and R. A. Vroom, Drs. Org. Chem., University of Leiden, Holland

[*Paper first received* 18 *January, and in final form* 3 *November*, 1954]

A description is given of an apparatus to determine the lifetime of phosphorescent light. The change of light intensity with time is compared with a variable exponential function on an oscilloscope. The constants of the exponential give the lifetime of the phosphorescent light.

PRINCIPLE OF OPERATION

Organic substances with one or more double bonds, when dissolved in a glassy solvent, show an after-glow when irradiated with ultra-violet light. The intensity of this phosphorescence decays exponentially with time,(1) the lifetime being dependent, among other factors, on the structure of the substance.

To obtain the phosphorescent light, the sample is placed between two half-sectors mounted on the same shaft. The first of these admits the exciting light while the other one shuts off the photocell. After half a revolution, the situation is reversed and the phosphorescent light can enter the measuring equipment. In this way no disturbance can be obtained from direct excitation or fluorescent light.

Normally, the lifetime is measured by analysing the photograph of an oscilloscope trace, the vertical component of which is proportional to the phosphorescent light intensity, while the horizontal component consists of a linear sweep. The trace can be marked by applying timing pulses of suitable duration and interval to the grid of the cathode-ray tube. These pulses will appear as bright spots on the screen.

Using modern electronic circuits, the accuracy in lifetime easurements can be improved, while at the same time easurements and evaluations can be made much quicker. range and Henderson[2] developed an apparatus in which e exponential decay of light from inorganic phosphors was easured with the help of a special oscilloscope tube with ur sets of electrostatic deflexion plates. However, such bes are not readily available and in looking for an alterna- e a more satisfactory method was developed.

---

* Now at Duke University, Durham, N.C., U.S.A.

A block diagram illustrating this new method is given Fig. 1. An electronic switch applies two exponentials multaneously to the Y deflexion-plates of the oscilloscope; e from the multipler tube, the other from a circuit that nerates exponentials with continuously-variable amplitude d lifetime, synchronized by the same shutter that exposes e phosphorescent light. In a measurement, the first step to obtain the phosphorescence pattern on the screen. The utter is rotated with a convenient speed, dependent on the etime; then the sweep is set at the double frequency. While oking at the screen the amplitude and decay time of the ponential generator are varied, until both curves overlap ig. 2). From the constants of the generator, the lifetime n be derived immediately. In this way, the photographic ethod is eliminated, saving a considerable amount of time d trouble, as no later interpretation of pictures is necessary d there is an immediate control on the shape of the curve, ving an indication of the purity of the substance.

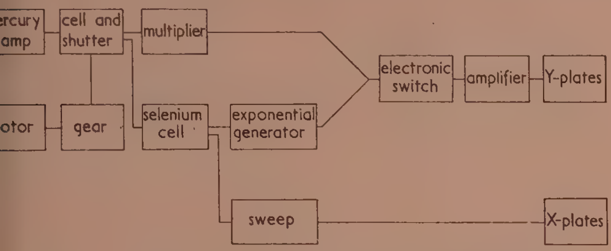


Fig. 1. Block diagram for the improved method

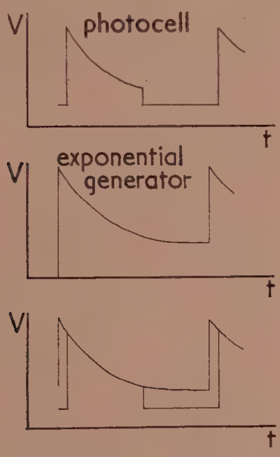


Fig. 2. The voltage/time curves for photocell and exponential generator

APPARATUS

Measuring cell and shutter. The measuring cell consists of ransparent quartz Dewar vessel filled with liquid nitrogen, which is placed a quartz test tube with an ether-isopentane-alcohol glassy solution of the substance to be measured (5 vol. ether, 5 vol. isopentane and 2 vol. alcohol, all carefully purified so that the mixture itself does not, when frozen, produce perceptible phosphorescence). The cell is irradiated intermittently by a mercury lamp, Philips type SP 500 W, with internal mirror and quartz window. The radiation is filtered by a quartz cell, filled with a dilute solution of copper sulphate to absorb the heat rays. The solution circulates through the cell and a water-cooled vessel. A quartz lens focuses the light on the sample. Immediately after one shutter shuts off the exciting light, the other one opens the phototube. Both shutters are mounted on the same shaft and are slightly more than semi-circular in order to avoid direct mercury and fluorescent light entering the photocell. The shutters are rotated by an electric motor. A continuously-variable gear is coupled between the motor and shutter-shaft. Two large disks are mounted opposite each other, one coupled to the motor, the other one to the shutter. The centre of the first disk is just opposite the edge of the second. These disks are coupled by a small rubber wheel that can be moved radially between them. The transmission becomes quadratically regulated in this way. It gives a continuously-variable shutter speed in a 100 : 1 ratio. For greater variations two wheels coupled by a rubber cord can be changed. These wheels are mounted between gearbox and shutter shaft. With this arrangement the shutter speed can be varied from 0·3 to 6000 c/s.

The photomultiplier. The phototube is a multiplier type 1P22. As it is undesirable to have high tension wires running from the phototube mount to the power supply, and moreover, since a stable adjustment at various sensitivities is required, a Greinacher circuit is built in the phototube housing. The wiring diagram is shown in Fig. 3. The rectifiers are of the selenium type, Westinghouse type 16K8, and

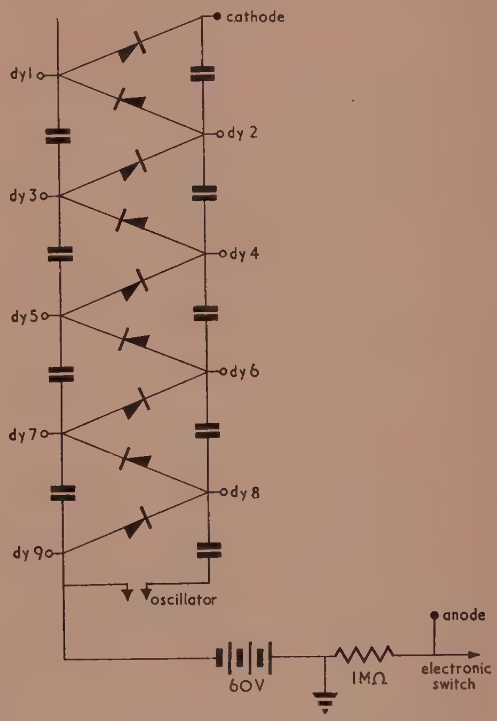


Fig. 3. Diagram of the phototube supply

Capacitors: 1 μF 400 V oil; Cells: Westinghouse 16K8.

rectify and multiply the a.c. supplied by a 100 kc/s generator. This frequency is preferred over normal 50 c/s operation, because it falls outside the pass band of the amplifiers used. The generator itself consists of a triode oscillator (6J5) in a conventional Clapp circuit, followed by a beam tetrode output amplifier (1622) with tuned transformer load. While cathode and dynodes of the photomultiplier are fed by the Greinacher circuit, the anode is fed by a 60 V battery to avoid hum pickup.

The exponential generator. The wiring diagram of this generator is given in Fig. 4. Consider the network of tube V_3. Normally, the tube is cut off, but when the grid is given a positive pulse of short duration the tube will conduct and condenser C_3 will be charged (Fig. 5; V_{g3} and V_{g4}). At the end of the pulse the grid drops to earth potential and the tube is cut off again. Now C_3 starts to discharge through R_7. The voltage over C_3 is a function of time and can be represented by

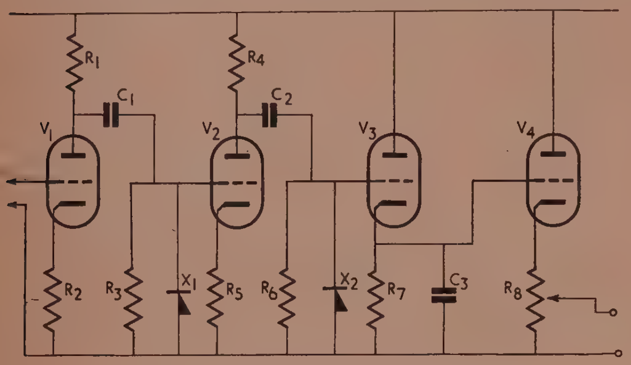


Fig. 4. The exponential generator

$R_1 = 470\ \text{k}\Omega$
$R_2 = 66\ \text{k}\Omega$
$R_3 = 2,2\ \text{M}\Omega$
$R_4 = 470\ \text{k}\Omega$
$R_5 = 66\ \text{k}\Omega$
$R_6 = 2,2\ \text{M}\Omega$
$R_7 =$ see text
$R_8 = 10\ \text{k}\Omega$

$C_1 = 0{\cdot}002\ \mu\text{F}$
$C_2 = 0{\cdot}002\ \mu\text{F}$
$C_3 =$ see text
$X_1 =$ 1N34
$X_2 =$ 1N34
$V_1, V_2 =$ 6SL7
$V_3, V_4 =$ 6SN7

$$V_c = a.\exp\,(-\,t/R_7C_3)$$

in which a is a constant, depending on the circuit.

The exponential will last from the end of a trigger pulse until the beginning of the following one. Therefore it is advisable to arrange for the triggering pulses to occur before the shutter opens the multiplier tube. This can be done conveniently by placing a selenium photocell on the measuring-cell housing beside the multiplier, so that the selenium cell is exposed by the shutter before the light can enter the multiplier tube. The signal coming from the selenium cell is amplified, differentiated and clipped, producing the waveforms shown in Fig. 5; V_{g1} and V_{g2}. The pulse on V_{g3} can, at the same time, be used to synchronize the sweep of the oscilloscope.

When the traces of both exponentials overlap, the decay constant of the phosphorescent light equals $(R_7C_3)^{-1}$. By taking R_7 in steps each differing by a factor of 10, and C_3 continuously variable, a range of decay times can be generated between about 10 and 10^{-5} s.

Timing pulses. Timing pulses are used to check sweep linearity in the photographic method, and while not strictly necessary in the new method, they are helpful in checking stability and give a quick, though rough, estimate of frequency. The timing unit produces pulses that can be used to modulate the intensity of the oscilloscope trace at exactly known time intervals. A multivibrator type tuning-fork oscillator operates at 500 c/s, synchronizing a type 6SN7 multivibrato with fundamental frequency at 1 kc/s. This multivibrator i the first in a series, operating respectively at 1 kc/s, 100, 10 1 and 0·1 c/s.(3) One of these frequencies can be chosen t modulate the trace.

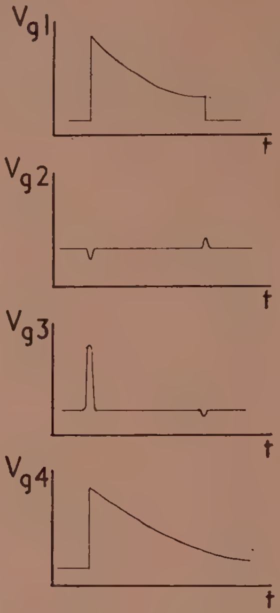


Fig. 5. The grid voltage/time curves of V_1 to V_4 in Fig. 4

Amplifiers. The Y deflexion-amplifier is a "starved" amplifier, i.e. a pentode with an anode load resistance of te or more times the normal value, while the screen voltage is lowered to about 10 V. Under this condition, the gain ca be two to three thousand.(4) This amplifier is followed by a double triode push-pull output stage. It is coupled d.c. throughout (Fig. 6). The pass-band of "starved" amplifiers is not very high according to the high anode load resistance but the frequency response can be kept sufficiently flat fo the exponentials to be observed, while, on the other hand any possible 100 kc/s output from the multiplier will b eliminated.

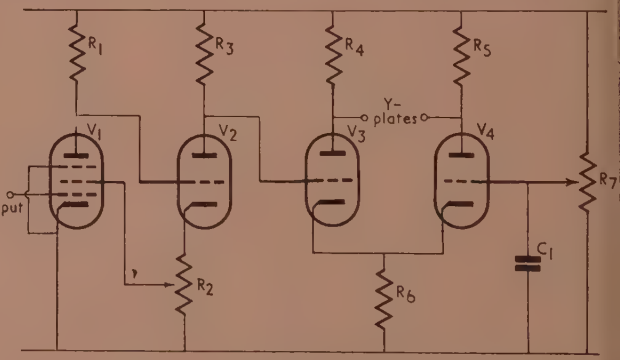


Fig. 6. The Y deflexion-amplifier

$R_1 = 22\ \text{M}\Omega$
$R_2 = 2150\ \Omega$
$R_3 = 100\ \text{k}\Omega$
$R_4 = 82\ \text{k}\Omega$
$R_5 = 82\ \text{k}\Omega$
$R_6 = 27\ \text{k}\Omega$

$R_7 = 300\ \text{k}\Omega$
$C_1 = 2\ \mu\text{F}$
$V_1 =$ 6SJ7
$V_2 =$ 6C5
$V_3, V_4 =$ 6SN7

DISCUSSION

The advantages of the new method of measuring the iosphorescence lifetime are threefold. First, lifetimes can e measured easily and more quickly. Second, the accuracy improved compared with the former method, as any ossible errors in sweep linearity and photographic repro- uction are eliminated and the exponential can be achieved ery precisely by using standard resistors and capacitors. hird, there is a close control on the shape of the curve.

A relative accuracy of 2·5% is obtained by using a fixed pacitor and a normal carbon potentiometer. After each easurement the resistance was measured with an AVO odel 8 meter (by Automatic Coil Winder and Electrical quipment Co. Ltd.). The accuracy is expected to fall below % when fixed standard resistors and a calibrated variable recision capacitor are used, as in that case no separate - or *C*-measurements are needed.

Mixtures of two phosphorescent substances that give a different lifetime will produce patterns that are non-exponential. These curves could be compared with the sum of two independently generated exponentials.

The apparatus is very sensitive, and great care should be taken to purify all ether-isopentane-alcohol compounds, and to redistil just before use. Even small traces of oil in the liquid nitrogen are apt to give a phosphorescent light that can disturb measurements. The quartz test tube should be glowed before use to destroy all phosphorescent material.

REFERENCES

(1) McClure, D. S. *J. Chem. Phys.*, **17**, p. 905 (1949).
(2) Strange, J. W., and Henderson, S. T. *Proc. Phys. Soc.* [*London*], **58**, p. 369 (1946).
(3) Attew, J. E. *Wireless World*, **58**, p. 114 (1952).
(4) Volkers, W. K. *Electronics*, **24**, p. 127 (1951).

A single-profile crystal extensometer adjustable for orientation

By A. J. Kennedy, Ph.D., A.M.I.E.E., F.Inst.P., The British Iron and Steel Research Association, London, S.W.11

[*Paper first received* 13 *October*, 1954, *and in final form January*, 1955]

The use of profile-type extensometers for the creep testing of metal single crystals of a fixed initial length is limited by the fact that a particular profile is required for any given original crystal orientation (ϕ_0). The device described uses a single profile which is set for ϕ_0 by simple rotation, the magnitude of this rotation being linear with ϕ_0. Crystals with values of ϕ_0 from zero to 50° can be tested with a stress variation of less than 1·5% over an extension of 100%.

n the creep testing of solids, devices are commonly used to aintain the stress constant as deformation proceeds. A umber of different types of device have been developed, and ese have been classified and summarized in the introductions o former publications,(1) as well as being comprehensively eviewed elsewhere.(2) The deformation of single crystals is a particular case of this general problem, the criterion here being that the resolved shear stress on the glide planes, in the glide direction, shall remain constant as the crystal extends. This means that the device must automatically compensate for the effect brought about by the rotation of the glide planes with respect to the specimen axis. The geometry of the problem if only one set of planes is operative (as in hexagonal crystals) may be stated as follows.

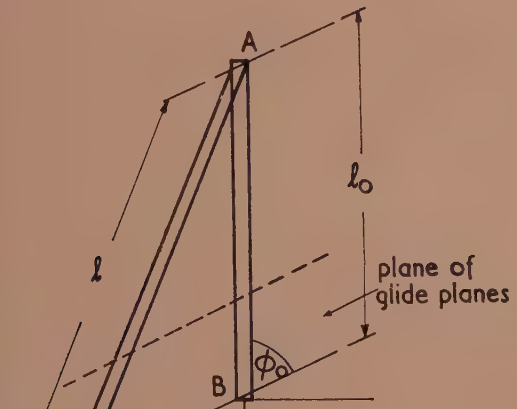


Fig. 1. The geometry of the crystal extension. In the usual testing methods employing profiles the crystal is, of course, extended along a fixed line (*AB*)

If the original crystal length is l_0 and if the glide planes make, initially, an angle ϕ_0 with the geometrical (tensile) axis, then (Fig. 1) the angle between the planes and the specimen axis, after an extension from l_0 to l is ϕ, where (from elementary geometry)

$$l \sin \phi = l_0 \sin \phi_0 \qquad (1)$$

The shear stress imposed on the glide planes at any instant $= W \cos \phi / A$ where W is the tension applied to the specimen. Initially this shear stress $= W_0 \cos \phi_0 / A$, where W_0 is the value of the loading weight and A is the area of a cross-section parallel to a glide plane. For constancy of stress,

$$W_0 \cos \phi_0 = W \cos \phi \qquad (2)$$

In a profile device this change of tension is brought about by the line of application of the weight moving towards O as the crystal extends. From Fig. 2(*a*), the tension W applied when the device has rotated through θ is $W_0 p / l_0$ where the radius of the circular profile is made equal to the initial specimen length l_0, and p is the vertical distance of the tangent DE from O. The required constant stress condition is thus

$$p / l_0 = \cos \phi_0 / \cos \phi \qquad (3)$$

Now ϕ is a quantity which is not directly measured, so we use equation (1) to obtain

$$p/l_0 = \cos\phi_0[1 - (l_0^2 \sin^2\phi_0/l^2)]^{-\frac{1}{2}}$$

and as $l = l_0 + l_0\theta$, we have

$$p = l_0 \cos\phi_0\{1 - [\sin^2\phi_0/(1+\theta)^2]\}^{-\frac{1}{2}} \tag{4}$$

We thus have an equation relating p to θ, and the required profile may be obtained, for any given value of ϕ_0, by drawing the envelope to a series of tangents constructed according to equation (4). This is fairly standard practice, the disadvantage being that for a given crystal length, l_0, a different profile is required for each orientation ϕ_0. To overcome this, certain workers(3) have constructed a number of profiles (in some cases as many as seven) and have used the one nearest to that of the crystal under test. A device with a flexible profile, enabling this to be adjusted for orientation with reasonable accuracy, has been proposed by Metzger.(4) Devices such as these are based on the supposition that the rotation of the planes is uniform throughout the specimen, whereas, because of the restraints imposed by the end groups, this is not strictly true, and Rosi(5) has reduced the error by incorporating gimbals on to the end attachments. Another approach is that of deliberately constraining the movement of the ends of the crystal to lines parallel to the glide direction. This has been done in instruments by Bausch,(6) Rohm and Kochendörfer(7) and Kennedy.(8) Although these methods possess advantages, the problem of frictional errors is now much greater. For delicate low-stress testing a profile device is the only way of eliminating these errors altogether, and some means is therefore required of avoiding the construction of a number of profiles. One way of doing this is to use a single high-angle profile (say $\phi_0 = 70°$), and to vary the initial length (l_0) of the crystal so that $l_0 \sin\phi_0$ remains constant. On this basis, a profile correct for $\phi_0 = 70°$ and $l_0 = 10$ cm could be used for $\phi = 10°$ if $l_0 = 55$ cm. This is clearly unacceptable, and a circular profile of smaller radi would be required; this in turn would involve shifting t apparatus with respect to the crystal position, which is usual fixed within a furnace of some kind. A solution on these lin is certainly possible (although there appears to be no accou of its use to date) but it is not an answer to the problem producing a device for testing single crystals of some fixe initial length in such a way that a single simple adjustme will take account of l_0.

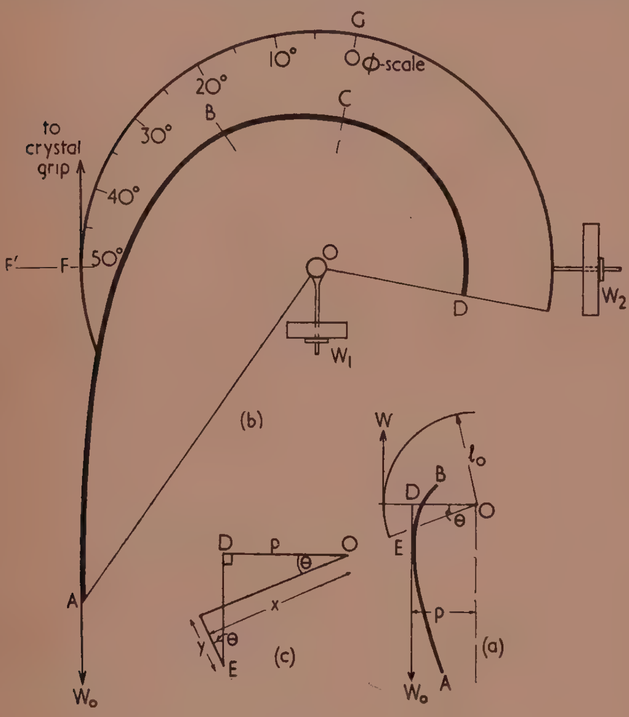


Fig. 2. The geometry of the device

This paper describes a device which uses one profile onl and may be set for the ϕ_0-value required by rotating th profile about the pivot relative to some fixed line.

DESIGN OF THE DEVICE

As has been said, the required profile for any particula ϕ_0-value may be constructed using equation (4).

The profiles are usually constructed by this envelop method, but it is a more accurate procedure to convert th profile into Cartesian form. This may be effected in th standard way.

Thus, in Fig. 2(*a*), we take O as the origin, and the axe fixed to the cam, with x horizontal and y vertical whe $\theta = 0$. For a rotation θ, the tangent touches the cam at x and y being related [see Fig. 2(*c*)] by

$$y = x\cot\theta - p\,\mathrm{cosec}\,\theta \qquad ($$

where p is given by equation (4). By standard methods w solve for x and y.

Defining f by

$$f = y\sin\theta - x\cos\theta + l_0\cos\phi_0\{1 - [\sin^2\phi_0/(1+\theta)^2]\}^{-\frac{1}{2}} \qquad ($$

we differentiate to obtain

$$df/d\theta = 0 \qquad ($$

Solving for x and y from equations (6) and (7), we obtai

$$\left.\begin{aligned} x &= l_0\frac{\cos\phi_0}{F}\left[\frac{\sin^2\phi_0\sin\theta}{F^2(1+\theta)^3} + \cos\theta\right] \\ y &= l_0\frac{\cos\phi_0}{F}\left[\frac{\sin^2\phi_0\cos\theta}{F^2(1+\theta)^3} - \sin\theta\right] \end{aligned}\right\} \qquad ($$

where $F = \{1 - [\sin^2\phi_0/(1+\theta)^2]\}^{\frac{1}{2}}$

By convention, in Fig. 2(*c*), the distances x and y would b negative as drawn, the criterion being that both should b negative when $\theta = 0$. We therefore prefix both equations (above with negative signs in subsequent computations.

For any ϕ_0-value, the required profile may be calculate and plotted directly from equations (8). As this is a laboriou operation, and as numerical data have not previously bee published, values of x and y for seven ϕ_0-values are given i the table for a maximum θ (rotation) of 70°, and for a initial crystal length of 10 cm. The radius of the circula profile is also 10 cm. It will be evident that on this basis th profiles for 60° and 70° are impracticably large, and must b constructed specially on a reduced scale should they b required. In fact, for values of $\phi_0 > 50°$, such testing unsatisfactory anyway because of the very high geometrica softening which occurs (see Cottrell and Aytekin(3)). Thi results in an inhomogeneous deformation, with intense sli concentrated in a few isolated regions, and leads to a S-shaped creep curve. We limit our considerations, then, t the useful range of ϕ_0-values from zero to 50°.

Cartesian co-ordinates of constant stress profiles for different ϕ-values

φ \ θ		0°	2°	5°	10°	20°	30°	40°	50°	60°	70°
10°	x	$-10{\cdot}00$	$-10{\cdot}00$	$-9{\cdot}96_3$	$-9{\cdot}84_2$	$-9{\cdot}37_4$	$-8{\cdot}62_8$	$-7{\cdot}62_3$	$-6{\cdot}39_3$	$-4{\cdot}97_4$	$-3{\cdot}40_9$
	y	$+0{\cdot}03_1$	$+0{\cdot}69_6$	$+0{\cdot}63_1$	$+1{\cdot}54_2$	$+3{\cdot}28_0$	$+4{\cdot}88_3$	$+6{\cdot}31_7$	$+7{\cdot}54_8$	$+8{\cdot}54_3$	$+9{\cdot}27_6$
20°	x	$-10{\cdot}00$	$-9{\cdot}99_1$	$-9{\cdot}94_9$	$-9{\cdot}80_9$	$-9{\cdot}29_6$	$-8{\cdot}53_9$	$-7{\cdot}50_2$	$-6{\cdot}27_9$	$-4{\cdot}88_2$	$-3{\cdot}35_3$
	y	$-1{\cdot}32_5$	$-0{\cdot}83_1$	$-0{\cdot}13_4$	$+0{\cdot}94_2$	$+2{\cdot}85_8$	$+4{\cdot}53_9$	$+5{\cdot}98_5$	$+7{\cdot}20_9$	$+8{\cdot}18_9$	$+8{\cdot}90_8$
30°	x	$-10{\cdot}00$	$-9{\cdot}98_8$	$-9{\cdot}92_6$	$-9{\cdot}73_6$	$-9{\cdot}13_7$	$-8{\cdot}30_3$	$-7{\cdot}26_6$	$-6{\cdot}05_9$	$-4{\cdot}71_4$	$-3{\cdot}24_1$
	y	$-3{\cdot}33_4$	$-2{\cdot}56_8$	$-1{\cdot}54_7$	$-0{\cdot}11_6$	$+2{\cdot}15_5$	$+3{\cdot}95_6$	$+5{\cdot}43_8$	$+6{\cdot}64_6$	$+7{\cdot}60_8$	$+8{\cdot}27_7$
40°	x	$-10{\cdot}00$	$-9{\cdot}97_2$	$-9{\cdot}87_0$	$-9{\cdot}59_2$	$-8{\cdot}83_3$	$-7{\cdot}91_6$	$-6{\cdot}86_3$	$-5{\cdot}68_5$	$-4{\cdot}40_8$	$-3{\cdot}04_6$
	y	$-7{\cdot}04_4$	$-5{\cdot}58_4$	$-3{\cdot}84_7$	$-1{\cdot}69_3$	$+1{\cdot}19_9$	$+3{\cdot}18_4$	$+4{\cdot}69_7$	$+5{\cdot}87_2$	$+6{\cdot}77_4$	$+7{\cdot}40_6$
50°	x	$-10{\cdot}00$	$-9{\cdot}94_0$	$-9{\cdot}73_8$	$-9{\cdot}27_4$	$-8{\cdot}27_5$	$-7{\cdot}26_4$	$-6{\cdot}21_2$	$-5{\cdot}10_5$	$-3{\cdot}94_4$	$-2{\cdot}73_3$
	y	$-14{\cdot}20$	$-9{\cdot}89_3$	$-7{\cdot}39_2$	$-3{\cdot}79_2$	$+0{\cdot}08_5$	$+2{\cdot}28_8$	$+3{\cdot}79_9$	$+4{\cdot}91_0$	$+5{\cdot}72_7$	$+6{\cdot}29_2$
60°	x	$-10{\cdot}00$	$-10{\cdot}00$	$-9{\cdot}69$	$-8{\cdot}92_5$	$-7{\cdot}58_4$	$-6{\cdot}21_8$	$-5{\cdot}42_6$	$-4{\cdot}41_8$	$-3{\cdot}40_0$	$-2{\cdot}37_5$
	y	$-37{\cdot}76$	$-25{\cdot}53$	$-15{\cdot}84$	$-8{\cdot}02_8$	$-1{\cdot}77_4$	$-1{\cdot}39_0$	$-2{\cdot}57_7$	$-3{\cdot}65_8$	$-4{\cdot}40_9$	$-4{\cdot}91_4$
70°	x	$-10{\cdot}00$	$-9{\cdot}45_0$	$-8{\cdot}38_7$	$-7{\cdot}11_9$	$-5{\cdot}61_5$	$-4{\cdot}63_8$	$-3{\cdot}83_1$	$-3{\cdot}08_5$	$-2{\cdot}36_0$	$-1{\cdot}63_9$
	y	$-75{\cdot}51$	$-36{\cdot}75$	$-17{\cdot}82$	$-7{\cdot}48_5$	$-1{\cdot}49_6$	$+0{\cdot}65_5$	$+1{\cdot}82_2$	$+2{\cdot}57_2$	$+3{\cdot}08_2$	$+3{\cdot}42_0$

The complete profile is shown in Fig. 2(*b*). From *A* to *B* the profile is the $\phi_0 = 50°$ curve of the table, *B* being the point for $\theta = 60°$. From *C* (for which $\theta = 100°$) to *D* the curve forms the quadrant of a circle of radius $R = 6{\cdot}4$ cm. These two curves are connected by the curved section *BC* which has been obtained empirically. The device is set for ϕ_0 by simple rotation about *O* with respect to a fixed horizontal line (say the line *FF′*). A graduated scale *FG* is shown, covering 100° of rotation, with the numerals indicating units of 2° of rotation. This is the ϕ_0 setting scale and it reads ϕ_0 directly. Thus a linear relationship exists between the quantity to be set (ϕ_0) and the setting movement (rotation of the device); the form of the curve *BCD* was designed deliberately to bring about this linearity.

The centre of gravity of the device is brought into coincidence with the pivotal point *O* by adjusting the two weights W_1 and W_2.

Once the value of ϕ_0 for the particular crystal is known, then the starting-position of the system may be set using the ϕ_0-scale. The actual shear stress, for a given loading weight, clearly depends on the initial ratio p/l_0 [Fig. 2(*a*)]. Each initial setting therefore introduces a simple stress factor which can be tabulated if required, or it can be found directly by the use of a fixed linear horizontal scale from which the distance *p* can be read off. The problem is simply that of determining the initial moment.

The device is theoretically exact for the case $\phi_0 = 50°$ over the range from $\theta = 0$ to $\theta = 60°$, and for the case $\phi_0 = 0°$ from $\theta = 0$ to $\theta = 90°$. Intermediate values of ϕ_0 may be ested in the range from $\theta = 0$ to $\theta = 70°$, with a stress variation of less than 1·5%. For smaller ranges of θ (less otal extension), the constancy of stress is correspondingly mproved; for instance, in the range $0 < \theta < 30°$, the error s less than 1%. The accuracy of the device is demonstrated n Fig. 3. The points plotted were obtained in the following way. The profile of Fig. 2 was set by rotation for a particular ϕ_0-value. The true profile for ϕ_0 was then reduced in scale o that it was coincident with the set profile at $\theta = 0$. A ew points along the (exact) reduced profile were then plotted. t will be seen how closely these lie to the adjustable profile, nd how accurately, as a consequence, the device can eproduce the required profile for any particular ϕ_0-value. Unless very special constructional methods are used, a profile which is theoretically exact for a particular ϕ_0-value would ot, in practice, be better than 0·5%, and in any case, errors necessarily arise because of the non-uniform nature of the crystal deformation. The material is not, in fact, being subjected to a simple uniform shear, and there is usually some bending at the grips unless gimbals are used. The device described, then, is certainly accurate enough for this type of creep testing.

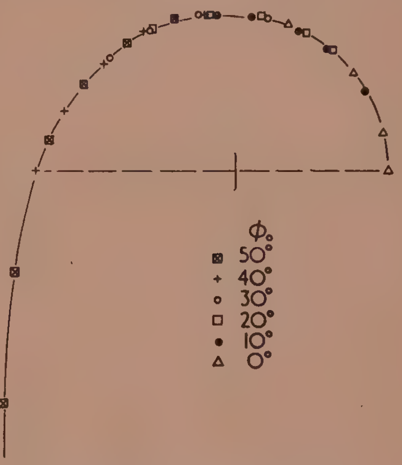


Fig. 3. Demonstrating how closely computed points for different ϕ_0-values lie to the designed profile shown by the line

REFERENCES

(1) Kennedy, A. J. *J. Sci. Instrum.*, **29**, p. 40 (1952); **30**, p. 371 (1953).

(2) Kennedy, A. J. *Instrum. Pract.*, **7**, p. 879 (1953).

(3) Cottrell, A. H., and Aytekin, V. *J. Inst. Metals*, **67**, p. 389 (1950).

(4) Metzger, M. *Rev. Sci. Instrum.*, **22**, p. 1022 (1951).

(5) Rosi, F. D. *Rev. Sci. Instrum.*, **22**, p. 708 (1951).

(6) Bausch, K. *Z. Phys.*, **93**, p. 479 (1935).

(7) Röhm, R., and Kochendörfer, A. *Z. Metallkunde*, **41**, p. 265 (1950).

(8) Kennedy, A. J. *Rev. Sci. Instrum.*, **24**, p. 505 (1953).

A computing microphotometer for cell analyses

By S. Bourghardt, Prof. H. Hydén, M.D., and B. Nyquist, Institute of Histology, Göteborg C, Sweden

[*Paper first received* 2 *September, and in final form* 1 *November*, 1954]

A scanning and printing computing microphotometer for analyses of large quantities of tissue cells and cell structures is described. One pertinent problem in quantitative cytology using microspectrography within some range of the spectrum, is the time it takes to obtain quantitative data on specific substances from many measurements on each cell and then to repeat them on many cells in order to get statistically significant results. Every problem on differentiation, cell growth or function involves this difficulty, when the specimen is a section through a number of cells. With the apparatus 12 000 measurements can be made on an area 30 × 36 mm and the results are automatically computed and recorded in numbers point by point as they occur in the specimen. The area of the specimen covered by a single measurement is usually $3\mu^2$, and an ultimate resolution of 1μ is possible. Due to a special control system every detail within the microscopic image can be localized and measured separately.

PRINCIPLE OF THE APPARATUS

The computer is a type of information machine, and has been developed from a microphotometer for microradiographic analysis already described.(1) It consists of an optical section, a scanning mechanism for the biological sample, a part for the conversion of light intensity into pulses with control units, a memory mechanism with controls and a printing unit. By means of a scanning system, the biological sample—usually a section through a number of cells—is divided into 12 000 measuring points. The light intensity is recorded in every measuring point. The amplitudes from the phototube are converted into pulses per unit time, which are counted and stored into a memory mechanism. From here, the scanned transmission values are printed with maintained spatial localization, and can then be integrated over the measured area of the sample. The computer is intended for direct measurements on the biological sample or on finely-grained films, such as the Lippmann film with a resolving power down to 1 μ, in the cases where the sample is photographed on such a film.

FIELD OF USE

The reason for which this computer was constructed is as follows. During the past fifteen years, an increasing number of so-called quantitative cytological or cytochemical methods have been developed. Microspectrography using ultraviolet or X-radiation in order both to localize and to determine specific substances within cells or parts of the cell may be mentioned as an example. However informative these methods may be in dealing with cell physiological problems, they are nevertheless handicapped by the time required to obtain quantitative data from *a large number of cells*. The minimum number of cells which must be investigated in order to obtain statistically significant results is obviously a fundamental problem in these methods. A good example is differentiation and growth problems in cancer research. The investigation of the central nervous system with cytochemical methods provides another illustration. The brain tissue has a low volume percentage of cells. Moreover, the nerve cells have elongated processes which build up a three-dimensional network characteristic of nervous tissue. Consequently, they do not lend themselves easily to differential centrifugation for the purpose of obtaining large quantities of isolated cells.

GENERAL CONSTRUCTION

Fig. 1 shows the computer. The microscope *M* is a Leitz Ortholux; its mechanical construction is stable and of a good
degree of accuracy. Its accuracy has already been tested.(2
During the measurements the biological section remai
attached to the table. The light source used in dens
measurements of microscopical sections, films or plates is

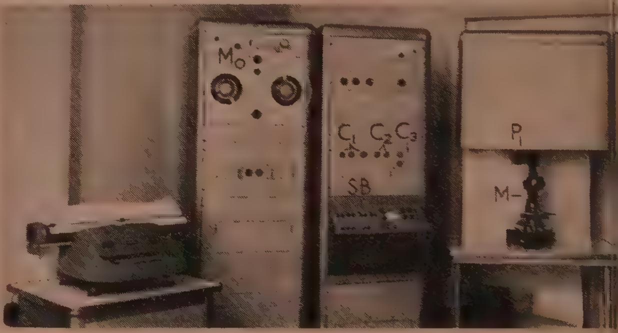


Fig. 1. View of the apparatus

M, microscope, mounted into the scanning unit; *P*, camera; *SB*, switchboard of the computing unit; C_1, C_2, C_3, dekatron tubes; M_0, memory unit.

low-voltage lamp fed from an accumulator. The opt
consist of Leitz apochromates together with peripla
oculars and with the condenser adjusted according to Berek.
Every sample is photographed before the measurements, a
the picture is projected optically over the transmission da
obtained after each complete set of measurements, whi
are printed on the 45 × 45 cm paper. For this purpose t
instrument is provided with a camera *P* for 6 × 9 cm pla
or films.

The light intensity from the sample is measured by
scintillation tube, RCA 5819 (Fig. 2, *ST*), mounted in
movable holder *H*. The position of the semi-transpare
cathode in relation to the steel band *B* of the scanning part
controlled visually. The scanning mechanism consists of
endless steel band *B*, 60 mm in width, and 0·051 mm
thickness perforated by small holes, 0·3 mm in diamet
The arrangement of these holes is shown in Fig. 3. T
holes in the band, which lies in a plane close to the surf
of the phototube, scan the biological sample line by line
120 lines. The magnification in the microscope is usua
arranged in such a way that one hole in the band cor
sponds to a measuring area in the sample of 3 μ^2. Whe
hole has been moved 100 diameters, one line with
measuring points is scanned. The scanned surface
30 × 36 mm, which area is thus divided into 12 000 measur

oints. The steel band is stretched between seven steering llers provided with ball bearings (*R*, Fig. 2). One of e rollers *G* bears teeth, which engage in the holes at the les of the band, and drive the band in a manner analogous that used for driving an ordinary cinema film. A second ller is spring-loaded and maintains the tension in the band. ne toothed roller is driven by a synchronous motor through 200 : 1 reduction gear. The velocity of the band is 15 mm/s. ne band is steered laterally by guides on a plate and is kept ane by means of pressure runners, the whole constituting single unit *RU*. Between the steel band and the scintillation be a lens system is introduced. At *PT* a second phototube, CA 931 A, is placed. Situated below the centre in the ndow of the tube is a narrow slit in the plate; it is provided th a cylindrical lens through which a light beam is thrown om the lamp *V* through a mirror. When a hole in the band s over the slit, another hole, 96 mm away, is beginning to n the measuring area. At this instant the light reaches e phototube *PT* and starts a synchronizing process.

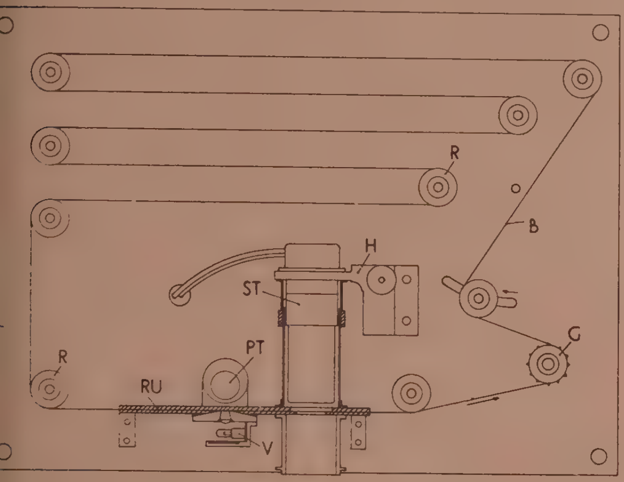


Fig. 2. Schematic drawing of the scanning system

B, steel band; *G*, roller with teeth; *H*, movable holder for scintillation tube *ST*; *PT*, phototube for synchronization; *R*, steering roller; *RU*, steering unit for the band; *V*, light source and lens system.

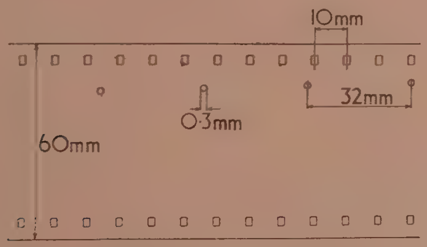
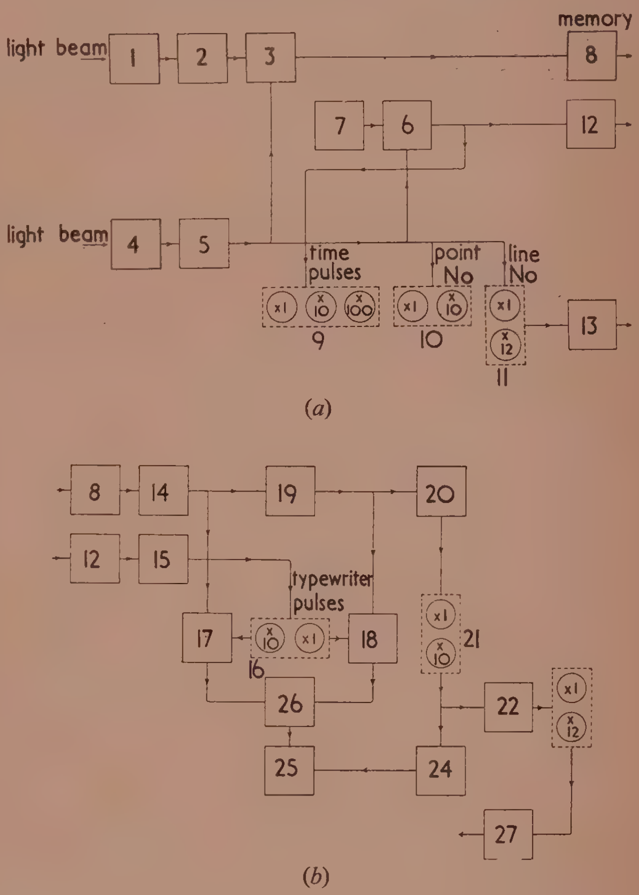


Fig. 3. Steel band

The d.c. generated in the phototube is modulated by a kc/s a.c. from a modulating oscillator (1) [Fig. 4(*a*)] and is rced on to a dynode in the phototube. The a.c. emitted m the phototube is amplified and rectified in an amplifier ector circuit (2). In this way d.c. amplitudes are obtained m every measuring point, and are proportional to the nsmission in the sample.

The amplitudes from each measuring point are converted means of a comparator (3) into pulse trains, the number of pulses in which are proportional to the value of the amplitudes. This is achieved in the following way. Alternating voltages are advanced from a sawtooth generator (3), of which the time lapse is synchronized with the velocity of the scanning mechanism. The 50 c/s mains is used as the master oscillator, and synchronization is effected through the synchronous motors of the driving mechanism in the computer. The pulse trains are stored in head II of the magnetic memory (12). See also Fig. 1, M_0.



(*a*)

(*b*)

Fig. 4. Simplified block diagram of the apparatus

1, photomultiplier 5819 and 10 kc/s modulation oscillator; 2, amplifier detector; 3, comparator and sawtooth generator; 4, photomultiplier 931 A; 5, gate circuit with operating unit and 50 c/s synchronized oscillator; 6, gate circuit; 7, 20 kc/s time pulse oscillator; 8, tape recording head I; 9, 10, 11, counters; 12, tape recording head II; 13, total stop circuit; 14, amplifier and trigger; 15, amplifier; 16, counter; 17, 18, cathode followers; 19, delay trigger; 20, trigger circuit; 21, counter; 22, trigger circuits; 23, counter; 24, carriage return trigger; 25, typewriter; 26, driving circuits for typewriter; 27, stop pulse circuit.

The necessary synchronizing process is arranged as follows. When light reaches the phototube 931 A (4), the gate circuits (5 and 6) are opened and the sawtooth voltage enters into the comparator (3), rising from zero until the same value is obtained as the amplitude from the phototube 5819. During the time occupied by this process, a 20 kc/s pulse oscillator (7) advances a certain number of pulses constituting the pulse train through gate (6). When the amplitudes have been comparated, a stop pulse is emitted from the comparator (3). This pulse closes gate (6), is recorded in head I of the magnetic memory (8) and restores the time-pulse counter (9) to the zero position.

The parts of this information machine hitherto described are provided with one advance control and one operation control. The advance control adjusts the sensitivity range of the computer to the light intensity in the sample in such a way that the information given by the apparatus on the transmission in the sample will lie between 0 and 100 and is therefore directly in per cent transmission. Three dekatron tubes are used for this purpose, one for unit, one for 10 and one for 100, respectively. [They are shown in Fig. 1, C_1, and Fig. 4(*a*), (9).] The operation control shows at each moment the number of measuring values which have been recorded. It also gives the localization in the sample of the last measuring value recorded. The two dekatron tubes [Fig. 1, C_2, Fig. 4(*a*), (10)] compute the number of measuring values per line. These are limited to 100 by means of a stop pulse to the synchronizing system. The scanned line in its turn has been concomitantly recorded in one ten-divided and one twelve-divided counter tube [Fig. 1, C_3, Fig. 4(*a*), (11)]. When the recording of twelve lines is completed, a stop pulse is emitted to that synchronous motor which drives the scanning mechanism, and to the synchronous motor of the magnetic memory.

At *SB* in Fig. 1 is shown the operating panel from which the main part of the units is controlled. The dekatron tubes are adjusted in zero position from this panel and the oscilloscope, of which the screen is visible on the panel, is used during the control and for servicing the various units.

The time lapse for the scanning of the 12 000 measuring points of the sample and the recording of the information in the memory amounts to 4 min. The printing of the data recorded takes place twenty times more slowly than the recording. It is an advantage to operate this unit at a later time, this making it possible to scan a larger number of samples in one operation. The velocity of the printing depends upon that of the printer, which is 12 downstrokes per second. The printing device is arranged as follows. The pulse trains recorded in head II (12) are amplified and computed by the dekatron tubes at (16) in Fig. 4(*b*). Let us assume that the dekatrons stop in the position "63." The actual position of the dekatrons actuates the cathode followers [Fig. 4(*b*), (17), (18)] in such a way that a thyratron relay for each of these figures effects the downstroke of the printer. When the same figure occurs twice, the same key is operated twice. The time lapse in the downstrokes is controlled in the following way. The pulses from head I (8) are converted and delayed in trigger circuits [Fig. 4(*b*), (14), (19), (20)] in order to make the dekatrons emit their information in the right order. When the printing of one line (200 figures) is completed, the process is temporarily delayed for an interval corresponding to the time required for the printer carriage to return. This is effected by means of two dekatrons with trigger circuits [Fig. 4(*b*), (21), (24)] actuating a coil which, in turn, releases the return of the carriage.

When the 12 000 measuring values have been printed, all movable parts are stopped automatically. This is achieved by means of two dekatrons with their trigger circuits [Fig. 4(*b*), (22), (23), (27)]. When the image has been scanned and all transmission figures recorded and printed, a square of figures, 45 × 45 cm, is obtained, as shown in Fig. 5. The final step is to project an image of the biological sample over this square of figures and on the same scale. In this way, the transmission values for all the cells are obtained integrated over the cell surface and using the resolution allowed by the film or the image. In practice, this limit can be set at 1 μ. It is therefore easy to collect the required number of tran mission values for statistical treatment.

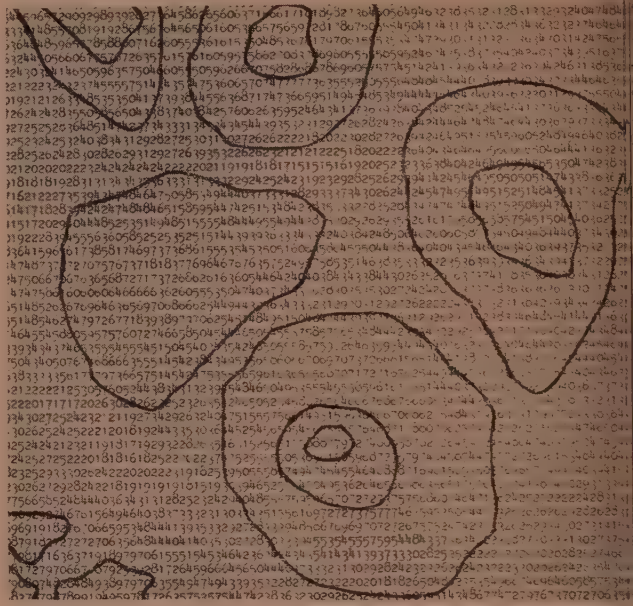


Fig. 5. Printed result of the scanning of a microscopic preparation

MECHANICAL AND ELECTRONIC CONSTRUCTIO

The microscope stands on a heavy-duty rack which als supports the scanning mechanism. The steel band and th steering rollers are mounted on a steel plate, 12 mm thicl The racks housing the electronic equipment are also heavy-duty construction in accordance with internation standards. All the chassis are made of aluminium. T

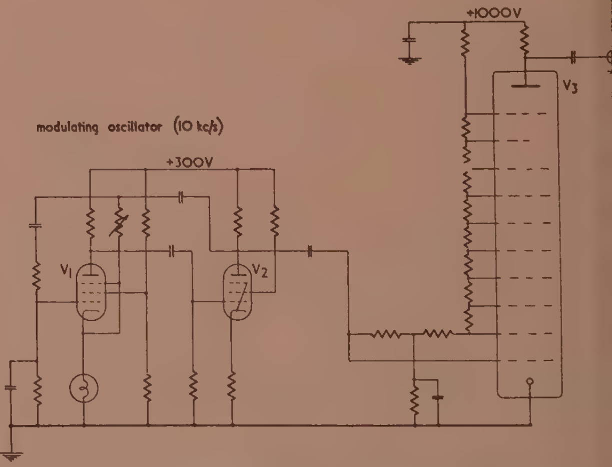


Fig. 6. Modulating circuits for the scintillation tube

facilitate inspection and access, as well as to permit a rap change of units, the electronic main system is built in twent two plug-in sub-units. In the middle of the aluminiu frame is mounted a high quality insulated plate, to whi e electronic components are attached. During the servicing e shutters on the front of the racks are removed (see Fig. 1).

On the back are control terminals for all the sub-units. uring the control, the oscilloscope seen on the switchboard SB in Fig. 1 is successively connected to the terminals of e various sub-units. The curve form on the screen is mpared with a correct curve for each sub-unit, a picture of ich is mounted at the terminals. Thus in routine work, ntrol of the function of the computer is a simple task.

The power supplies are placed in the lower part of each ck; the transformers and chokes are placed on one chassis d the rectifying and stabilizing tubes on another. The ses belonging to these units are assembled behind the utters on the rack. Small neon lamps signal if a fuse blows.

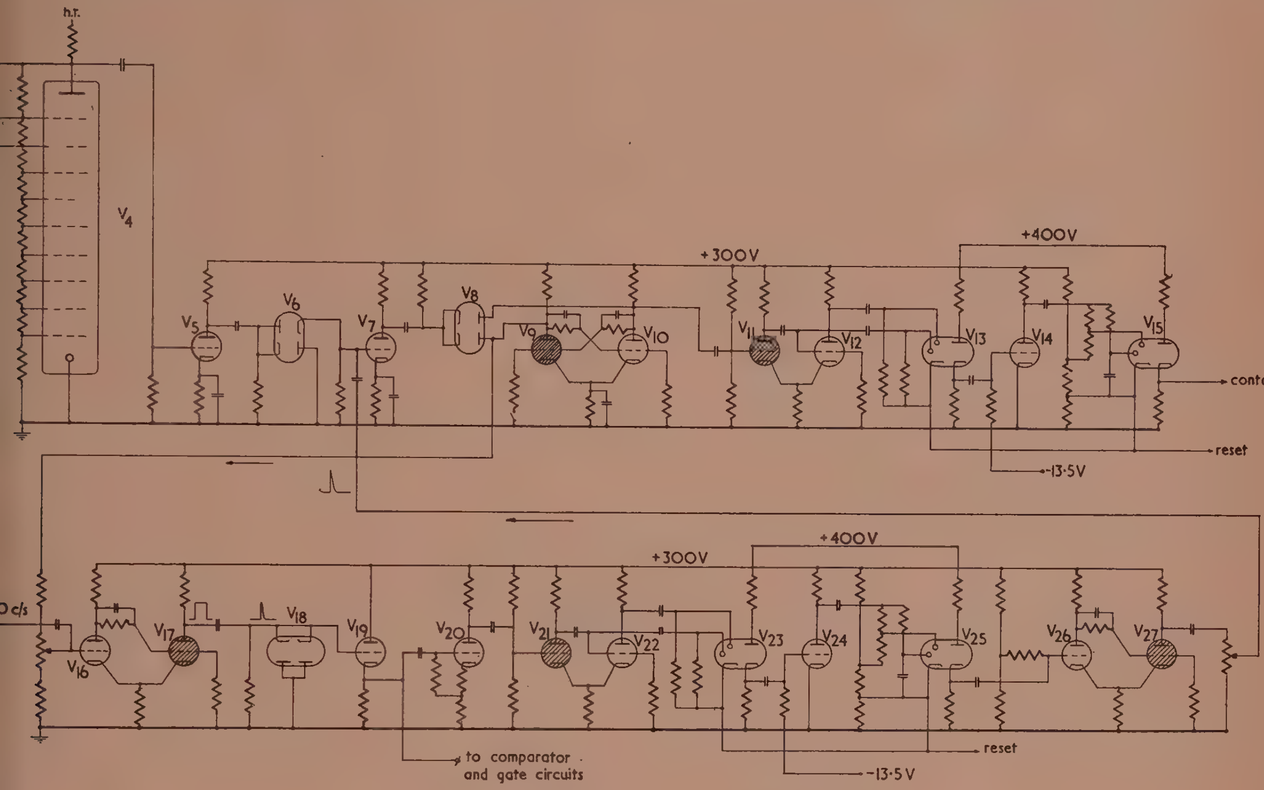


Fig. 7. Circuits of the synchronizing system

The following details may be mentioned with respect to the ctronic construction. The problem was to amplify the d.c. om the phototube without loss of linearity. Since the roduction of a d.c.-amplifier was regarded as too complited, the problem was solved instead according to the inciple shown in Fig. 6.

In order to obtain a synchronizing system which was both nple and automatic, the 50 c/s of the mains were used partly operate the synchronous motor and partly to generate nchronizing pulses (Fig. 7). The measuring procedure has en managed electronically as follows. V_{16}–V_{19} in Fig. 7 nstitute the pulse generator, and V_4 is the multiplier longing to the synchronizing procedure which occurs by eans of the bistable multivibrator at V_9–V_{10}. The same mechanism operates when the values from 100 measuring points have been recorded. (V_{23} and V_{25} indicate the number of measuring points being recorded.) V_{13} and V_{15} count the number of lines, and the output of V_{15} gives a pulse to the total stop circuit.

ACKNOWLEDGEMENTS

This apparatus has been made and the investigation has been facilitated by a special grant from the Swedish Government and by financial support from the Rockefeller Foundation. We acknowledge with thanks the assistance from Mr. L. Pilhage and Mr. S. Larsson at the Department of Histology. We are also indebted to Mr. E. Gisslén, the Swedish Ball Bearing Co., SKF, Göteborg, and Victor Hasselblad, Ltd., Göteborg, for valuable advice and help. A grant has also been given from the Swedish Cancer Society.

REFERENCES

(1) BOURGHARDT, S., BRATTGÅRD, S.-O., HYDÉN, H., JIEWERTZ, B., and LARSSON, S. *J. Sci. Instrum.*, **30**, p. 464 (1953).

(2) BEREK, M. *S.B. Gesell. Beförd. Ges. Naturwiss., Marburg*, **62**, p. 189 (1927).

(3) BRATTGÅRD, S.-O. *Acta Radiol.*, Suppl. 96 (1952).

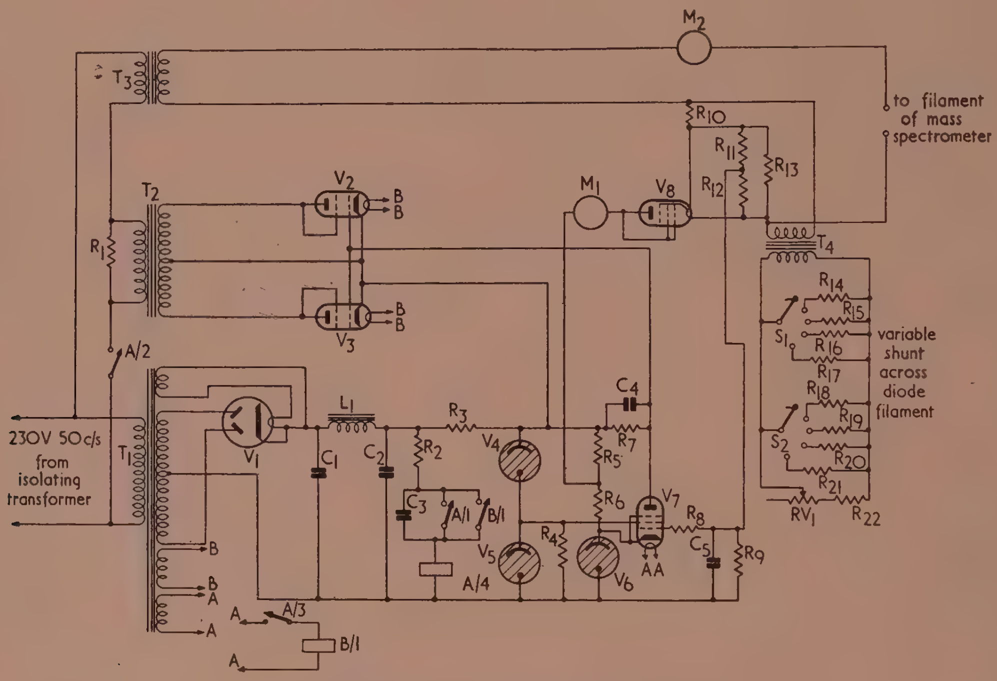
Laboratory and workshop notes

A stabilized current supply for a mass spectrometer, surface ionization, source

By K. L. Aitken, B.Sc., F. Hart, and P. Reynolds, B.Sc., Ph.D., Atomic Energy Research Establishment, Harwell, Berks

[*Note first received* 15 *July, and in final form* 27 *August*, 1954]

In the surface ionization source, which is being used to an increasing extent in mass spectrometry, a suitable chemical compound of the metal to be analysed for its isotopic composition is painted on a tungsten filament. This is heated, and for metals which have an ionization potential which is less than, or does not greatly exceed the work function of the surface of the filament, an appreciable positive ion emission may be obtained. The intensity of the ion beam obtainable is, however, very dependent upon the temperature of the filament, and hence the current heating it. This leads to the requirement of a filament current stability of the order of 1 part in 2000 in order that the intensities of the ion beams corresponding to various isotopes may be compared with an accuracy of ±1%. A voltage stabilized supply for this purpose has been described by Reuterswärd,⁽¹⁾ but this relies upon the resistance of the mass spectrometer filament circuit remaining constant. In spectrometers used in this laboratory, the filament is spot-welded to two nickel sleeves which are sliding fit on 1 mm diameter tungsten rods situated in th ion source, and connected to the filament current suppl This facilitates the changing of filaments, but introduces th possibility of variable contact resistance, and with th possibility in view the following current stabilizer wa developed.



Circuit diagram of filament current stabilizer

R_1 = 3·3 kΩ, 25 W, w.w.
R_2 = 27 kΩ, 4·5 W, w.w.
R_3 = 6 kΩ, 10 W, w.w.
R_4 = 100 kΩ, $\frac{1}{4}$ W, carbon
R_5 = 30 kΩ, 3 W, w.w.
R_6 = 2·2 kΩ, $\frac{1}{2}$ W, carbon
R_7 = 47 kΩ, $\frac{3}{4}$ W, carbon
R_8, R_9 = 100 kΩ, $\frac{1}{4}$ W, carbon
R_{10} = 10 Ω, 1$\frac{1}{2}$ W, w.w.
R_{11}, R_{12} = 270 Ω, $\frac{1}{4}$ W, carbon
R_{13} = 1·1 Ω, 1$\frac{1}{2}$ W, w.w.
R_{14}–R_{17} = 1·65 kΩ, 3 W, w.w.
R_{18},–R_{21} = 6·8 kΩ, 3 W, w.w.

R_{22} = 4·7 kΩ, 3 W, w.w.
RV_1 = 25 kΩ, 5 W, w.w.

C_1, C_2 = 8 μF, 600 V
C_3 = 0·1 μF, 500 V
C_4 = 0·25 μF, 250 V
C_5 = 0·02 μF, 200 V

M_1 = meter, moving coil, 1 mA full-scale deflexion
M_2 = meter, rectifier moving coil, 5A, a.c., full-scale deflexion

V_1 = CV378
V_2, V_3 = 6L6
V_4, V_5 = VR150/30
V_6 = 85A2
V_7 = EF37A
V_8 = 1T4 (CV785)

T_1 = primary 230 V, secondary 350–0–350 V, 60 mA
5 V, 3 A
6·3 V, 3 A
6·3 V, 1 A
T_2 = primary 230 V, secondary 400–0–400 V, 60 mA

T_3 = primary 170 V secondary 6·3 V, 5 A
T_4 = matching transformer 58 : 1 turns ratio

L_1 = 20 H, 60 mA

Relay A = 16 000 Ω coil. Contacts 2 make, 1 break
Relay B = Thermal delay relay. Heater 6·3 V, 5 A, 1 min delay

S_1, S_2 = Selector switch, single-pole 5-way, shorting contacts

The operation of the circuit shown in the figure depend upon the stabilization of the emission of the saturated diod V_8, the filament of which, suitably shunted, is in series wit the output of the circuit. The diode is a type 1T4 pentode connected as a diode, used by Attree⁽²⁾ in a circuit whic would give either voltage or current stabilization. Th filament was operated at the reduced current of 35 mA givi an emission of 0·9 mA at an anode voltage of 15 V. Th control circuit is of the conventional type, similar to that us

---

* *Note added in proof.*—More recent work has shown that t average type IT4 valve is much less stable than that used for t above tests, and that sudden changes in emission with corr sponding changes in output of up to 1% can occur. The ty CV1184 noise diode (now difficult to obtain) with a pure tungst filament does not suffer from this defect, and it has been used this laboratory in circuits of the above type (with R_{10} = R_{13} = ∞) for some years. A search for a similar alternative now being made.

stabilize the electron emission from ion gauge filaments,
st described by Ridenour and Lampson.(3) In this circuit
e impedance of the primary winding of transformer T_2 is
ntrolled electronically by the emission from the diode V_8.
nce the filament current of the diode is supplied by trans-
rmer T_3 the primary of which is in series with that of T_2,
emission is stabilized. The output current of the circuit
then dependent upon the value of the shunts connected
ross the diode filament. The requirement that the output
ould be variable over the range 1·8 to 4·8 A necessitated a
unt adjustable in the range 0·5 to 0·2 Ω. To avoid contact
sistance troubles in the sliding contacts of a variable
sistance of such a low value is difficult. The shunt is
mposed, therefore, of a fixed part R_{13} connected directly
ross the diode, and an adjustable part which is coupled to
e diode filament by a transformer T_4 having a turns ratio
58 : 1. The variable part of the shunt can therefore be of
gh resistance, and a standard rotary-type selector switch
n be employed for its adjustment. A thermal delay $B/1$
erates a relay, the contact $A/2$ of which prevents a voltage
ing applied to transformer T_3 before negative bias has
peared on the grids of valves V_2 and V_3. This eliminates
e initial large rise in output current that can occur before
e stabilizer begins to operate.

Using an unstabilized mains supply for the circuit it was
und possible to obtain an ion beam in a mass spectrometer
ble to ±1% for periods of the order of half an hour, which
rresponds to a current stability of ±0·02%. This is a
nimum figure for the stability, as some of the beam fluctua-
ns may have been due to variations in other parameters
the spectrometer. The stability against mains variations
er the whole current range except near the maximum current
s such that a change of ±10% in the mains supply voltage
oduced a change in output current of only ±0·02%. For
alteration of the resistance of the load from 0·3 Ω to 0·6 Ω
a current of 2·5 A a change in output current of only
15% occurred. At the maximum current of 4·8 A, the
cuit is capable of supplying an output voltage of up to 2 V
oviding the mains supply voltage does not fall by more than
% from its normal value.

REFERENCES

) REUTERSWÄRD, C. *J. Sci. Instrum.*, **29**, p. 184 (1952).
) ATTREE, V. H. *Electronic Engng*, **25**, pp. 27, 71 (1953).
) RIDENOUR, L. N., and LAMPSON, C. W. *Rev. Sci. Instrum.*,
8, p. 162 (1937).

Controlled water flows

By G. T. P. TARRANT, Ph.D., Canterbury University
College, Christchurch, New Zealand

[*Note received* 14 *July*, 1954]

ne "constant level apparatus" used in most teaching
boratories produces a controlled flow of water by the
plication of a variable pressure to the constant resistance
the apparatus and connecting tubing.

The alternative scheme of employing a constant water
essure and a variable resistance is complicated by the
fficulty of producing a simple resistance or tap which can
controlled reliably over a wide range.

The tap described below will, however, when used with
e "fixed level" apparatus shown in Fig. 1, deliver water at
tes varying over a range of 2000 : 1. Water entering from
e top tube can apparently reach the exit only by working
und the slight passages between the male and female parts of the thread. This is obviously a convenient principle to control the very slow flows desirable when the tap is turned nearly off, but cannot pass the desired large volume of water when the tap is turned on full. There are, therefore, four slanting slots milled in the male thread as shown in Fig. 2, so that the slot depth is large at the end and tapers to zero some five or six threads before the rubber O-ring is reached. In consequence when the tap is nearly open the water has to move through short deep slots, while, when half on, it has to move through a long length of tapering, shallow slots partially impeded by the female threads. Dimensional data is given in the legend of Fig. 1 and below.

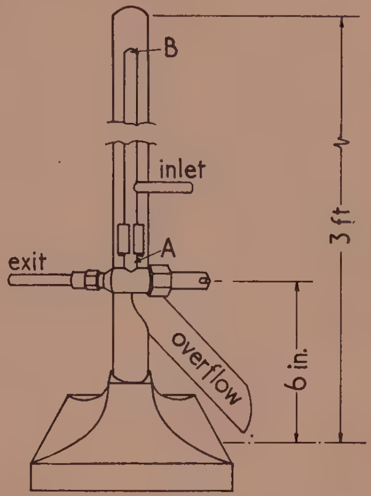


Fig. 1. Pictorial representation of complete apparatus

Upright tube AB 3 ft high and $\frac{1}{2}$ in. internal diameter; screw diameter $\frac{1}{2}$ in., $1\frac{1}{8}$ in. length threaded 26 turns per in.; four slots 1/16 in. wide cut at an angle of 12° with the axis and extending $\frac{3}{4}$ in. from the end of the screw.

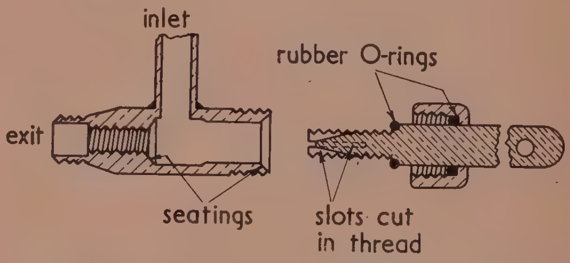


Fig. 2. Detailed expanded section of tap

Turns of tap	2	4	5	6	8	10
Rate of flow in cm³/s	0·02	0·03	0·05	0·32	0·59	1·18

Turns of tap	12	14	16	18	20
Rate of flow in cm³/s	5·7	17·0	26·1	36·2	46·0

These values happen by chance to be very roughly logarithmic, each turn increasing the flow by some 70%. The sensitivity of the tap at any particular range can obviously be altered by various expedients such as slightly reducing the diameter of the screw near to the O-ring, or filing very fine cuts where the normal slot has tapered away to zero.

Owing to the viscosity of water the pressure at the bottom of the tube AB increases slightly with the speed of the surplus water flowing up the tube to waste. This is small with the

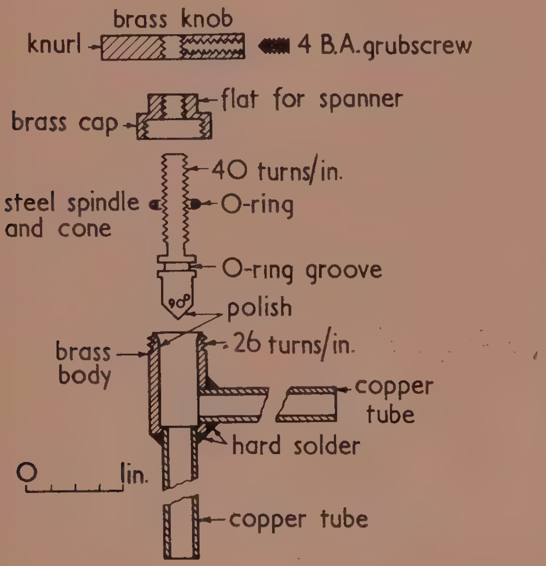
$\frac{1}{2}$ in. diameter tube but does amount to some 30% with a 9/32 in. internal diameter tube when the mains is delivering its maximum into the apparatus and to waste.

A simple metal-to-metal vacuum valve

By G. W. Green,* Atomic Energy Research Establishment, Harwell, Berks.

[*Note first received* 26 *October, and in final form* 20 *December*, 1954]

The various known types of metal-to-metal vacuum valves seem to be more or less complicated in design. The valve to be described, although simple and cheap to make, is nevertheless still entirely robust and reliable, and has a high pumping speed; the design was, in fact, suggested by the familiar gas cylinder valve. The use of a hard metal cone sealing on soft copper to effect a vacuum seal is not new,† but the essential feature of this valve (see the figure) is the use of the end of one of the connecting tubes as a seal, so that when the valve is closed its vacuum tightness on one side does not depend upon the O-ring gland, the soldered joints or any organic material. With the knob diameter and screw pitch shown it is not possible to overtighten the valve by hand, while very moderate effort will effect a seal.



Metal-to-metal vacuum valve

The use of an O-ring sets the temperature range of the valve, so that outgassing by baking is not possible. However, the valve has been found particularly useful in demountable counters which cannot be heated for constructional reasons, since its outgassing rate is lower than that of valves containing appreciable quantities of rubber for seals and seats. The use of a silicone O-ring should permit some heating for more rapid degassing. Because of its robustness and small size the valve has been used as a general replacement for more conventional vacuum valves.

The connecting tubes are of commercial copper, of the type used for plumbing, and are hard-soldered into the partly-finished brass body. The body is then bored out to the size required for the O-ring, and is continued so that the end the copper tube is flush with the end of the bore.

The moving portion is made in one piece, either of silv steel or stainless steel. The conical end therefore rotates wi the shaft instead of being free as is usual in metal-seale valves; this makes the construction much simpler and appea to introduce no disadvantages. The shaft thread pitch 40 turns/in. and the knob diameter 1½ in. for the valv illustrated, which has connecting tubes of ¼ in. nominal bo (actual bore size $\frac{11}{32}$ in.).

Several of these valves have been tested in both directio when closed, with a differential pressure of 4 atm. pressu of helium. In no instance were any leaks detected by commercial mass spectrometer type leak detector. O valve was tested after 1000 operations and showed no lea No attempt has been made to find the maximum pressure which these valves will operate, but it is probably much excess of the pressure at which these tests were made.

Other valves have been made in ⅛ in. and $\frac{1}{16}$ in. bore siz and have all proved satisfactory in service.

---

* Now at Radar Research Establishment, Malvern, Worcs.

† Alpert. *Rev. Sci. Instrum.*, **22**, p. 536 (1951); Brown and Coyle. *Rev. Sci. Instrum.*, **23**, p. 570 (1952).

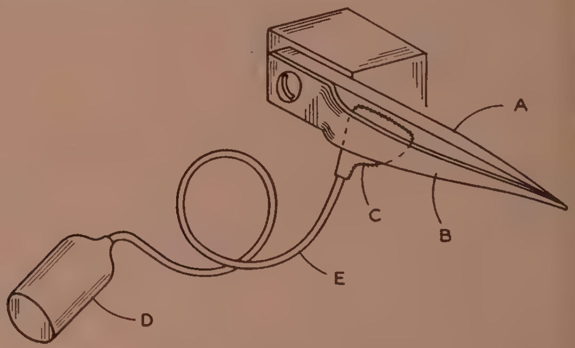
Pneumatic micro-tweezers

By J. I. Pankove, M.Sc., Radio Corporation of America, Princeton, New Jersey, U.S.A.

[*Note received* 20 *September*, 1954]

In micro-fabrication techniques a problem arose in releasi a fine gold wire delicately welded to a semiconductor witho breaking the weld. This problem was solved in the followi fashion.

The tweezers were mounted on a micrometric stage havi three degrees of freedom. One branch of the tweezers was rigid brass member *A* while the other branch consisted of phosphor-bronze leaf spring *B* which normally pressed again the rigid member. In order to open the tweezers, a Vinyli bag *C* inserted between the two members *A* and *B* wa inflated by squeezing a bulb *D* connected to the Vinylite ba through a flexible tube *E*. The Vinylite bag was hemmed an then fused to the plastic tube by means of an electrically heated wire loop.



Pneumatic micro-tweezers

This tool is quite satisfactory for gently gripping or releasi minute objects at very precise locations by remote contro Electrical connexion is made to the object while it is held b the tweezers. The tweezers were used to position a fi gold wire on to a selected region of a semiconductor crysta then the wire was bonded to the crystal by passing a sho pulse of current through the contact. After this weldi operation, the wire must be released very gently for the we is very fragile.

New books

ray diffraction by polycrystalline materials. Edited by H. S. Peiser, M.A., A.R.I.C., F.Inst.P., H. P. Rooksby, B.Sc., F.Inst.P., and A. J. C. Wilson, M.Sc., Ph.D., A.I.M., F.Inst.P. (London: The Institute of Physics, 1955.) Pp. 725. Price 63*s*.

is volume is the latest addition to the *Physics in Industry* ies of monographs.

t is divided into three parts: experimental techniques, erpretation of data, and practical uses of the techniques in ferent fields. It contains over 250 figures, many references d an Appendix which includes useful tables.

Its contents and purpose are well described by Sir Lawrence agg in his foreword:

"For anyone who has been concerned with X-ray analysis ce its early days, it is fascinating to see how the subject ntinues to grow and ramify. The present book is a striking istration of this development. Although it deals with only e branch of crystal analysis, the study of polycrystalline aterials, it has been found desirable to invite some thirty perts to make their contributions in order that each aspect the subject might be covered in an authoritative way. at it has been possible to weld contributions from so many thors into a coherent scheme is both a tribute to the editors d an excellent example of that happy collaboration that s existed from the very beginning amongst X-ray crystallo- aphers and continues so manifestly at the present time.

"The subject of this book is an important branch of X-ray ystallography because so many crystalline substances are ly available in a microcrystalline form and because a owder photograph' is a ready way of obtaining a record aracteristic of all the diffraction effects with a single posure. It is not surprising that, in industrial applications pecially, powder photographs are used to a far greater tent than the examination of single crystals.

"An interesting feature of this book is the series of essays the end, which show how the methods described in the rlier chapters can be applied in many different scientific lds. The earlier chapters deal with tactics, the latter with ategy. These essays, in addition to their interest to the pert, should also have a particular appeal to all who wish assess the potentialities of X-ray techniques in many anches of science.

"The lore of X-ray analysis by powder photographs, only be found otherwise in many journals and books, is here llected into a form in which it is readily accessible, and is book will be warmly welcomed by an ever-increasing mber of scientists."

as wärmetechnische Messwesen in Dampfkraftwerken und Industriebetrieben. By Dr. Ing. A. Ketnath. (Berlin: Göttingen: Heidelberg: Springer-Verlag, 1954.) Pp. ix + 222. Price DM 25.50.

is book on the instrumentation of steam power stations d industrial plant is divided into three parts. The first vers methods of measurement of temperature, pressure, ow, head, gas composition, electrical conductivity, pH, midity, rotational speed, measurement with remote indi- tion, and the principles of instrument construction. The treatment is concerned not so much with the detailed working of the devices as with their characteristics and suitability for various tasks. The second part deals with the planning of instrumentation systems by reference to the measurement and control problems arising in steam boiler plant, turbo-generators and compressors, pressure reducers, boiler feed plant, and industrial power stations. The third part concerns the external form of instrumentation systems, arrangement of indicators, suitable location of instrument panels, etc. The book may be thoroughly recommended to instrument designers who wish to see the subject from the point of view of the user, and to plant planning engineers who want guidance on the amount and type of instrumentation to install. At no point does the author forget that measurement is not an end in itself, but costs time and money which must be repaid by the value of the results.

D. B. Spalding

Optical instrumentation. Edited by G. S. Monk and W. H. McCorkle. (London: McGraw-Hill Book Co. Ltd., 1954.) Pp. xxv + 262. Price 28*s*.

This book comprises a collection of reports of work done by the optics section of a wartime "project" undertaken in the University of Chicago. Most of the devices described were intended for use in viewing objects made inaccessible by radiation screens. Considered as a contribution to the design of optical systems most of the book is unscholarly and amateurish. On the other hand it contains descriptions of some useful gadgets and laboratory practice. In particular, one may note the summarized results on the deposition of a great variety of metal films.

Speaking of the series in which this book appears, it is suggested in a foreword that "the scientific information in these pages may be the starting point to new reaches of knowledge, which will give to man an understanding that will truly enrich his life." One can only recall Dr. Johnson's phrase that "One must make allowance for hyperbolae."

H. H. Hopkins

Notes on applied science No. 5. Gauge making and measuring. (London: Her Majesty's Stationery Office, 1954.) Pp. 79. Price 3*s*.

This booklet, which is a second edition of the one published by the National Physical Laboratory in 1942, contains much valuable information concerning the manufacture and measurement of gauges. Parts I and II deal with the manufacture of gauges, including selection of steels, hardening, stabilizing and grinding, and this section concludes with a description of some special workshop methods which have been used at the N.P.L., such as a method for producing radii of curvature of any size, convex or concave.

Part III includes notes on the various types of measuring instruments commonly used, including slip gauges, micrometers, comparators, optical projectors, and other measuring tools. Part IV deals with the measurement of ring, gap and depth gauges, and taper plug and ring gauges.

The booklet cannot fail to be of interest and value to all concerned in any way with metrology.

M. Heywood-Hunt

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improv products. The Institute of Physics assumes no responsibility for the statements given below: information for these has be taken from literature supplied.

Solution excitation unit for spectroscopy. Research and Industrial Instruments Co., 12 Marlborough Yard, London, N.19.

The solution excitation technique using a rotating disk electrode was first suggested in 1940(1) and since that time has been successfully used for the estimation of many elements in a variety of liquids. In this technique the solution, as a film, is carried into the spark gap by means of a disk-shaped rotating electrode partly submerged in the liquid. The advantages of this technique are many and have been surveyed in the literature.(2, 3)

A solution excitation unit has been designed for this technique. A graphite disk electrode is carried by a stainless steel shaft which can rotate at any of the four speeds 4, 8, 12 and 16 rev/min by a pulley arrangement from a sturdy synchronous motor fitted at the back of the instrument. The shaft is mounted on two ball-races inside a rectangular ebonite block, and is connected to one of the input electrodes by means of two adjustable carbon brushes.

The upper electrode holder is of stainless steel and consists of a sleeve to take a graphite rod and a rack and pinion for adjusting the spark gap. The electrode holder can be rotated through 180° so that the graphite rod can be pushed into the sleeve, blunt end first. The holder is then rotated back until it clicks into its normal working position. This technique is devised so that, on loading, the tip of the vertical electrode is not contaminated by soot or residues, if any, from previous experiments.

The dish containing the liquid is placed under the rotating disk on an adjustable table. The instrument is also provided with a stainless steel pipe which may be connected to a filter pump to remove smoke, if necessary, and a plug through which a pipe for admission of gases may be introduced. The cover is in metal with suitable windows in front and on the two sides. The back and the base of the unit are covered on the outside with metal so that the unit is covered on all sides by metal to reduce electrical interference. The unit is usually supplied with a $\frac{3}{4}$ in. steel spindle to fit the most conventional types of spectrometer stands.

The electrodes normally supplied are disks of 9·5 mm diameter and 3 mm thick. They are drilled to fit the spindle and are cut from spectrographically pure graphite rods of 1 cm diameter, and for the top electrode from graphite rods of 6·5 mm diameter.

(1) Pierucci and Barbanti-Silva. *Nuovo Cimento*, **17**, p. 257 (1940).
(2) Pagliassotti and Porsche. *Anal. Chem.*, **23**, p. 1820 (1951); **24**, p. 1403 (1952).
(3) Key and Hoggan. *Anal. Chem.*, **25**, p. 1673 (1953); **26**, p. 1900 (1954).

Drip regulator. Boro' Laboratories and Appliance Co. Ltd., 1 Station Buildings, Catford, London, S.E.6.

The Condesco drip regulator is made in plastic which, it is claimed, resists the majority of dilute acids at room temperature. It has a wide-range, flow-control valve and a drip action which is fully visible. It has a capacity of 40 fluid oz and a working range of from 2 to 180 drops per minute. Its control rate, after an initial fall, stabilizes to $\pm 4\%$. As the reservoir empties the rate falls progressively but in general remains within dosage limits. The droplet content, below 50 drops per minute, is approximately 370 to 400 drops per fluid oz and, above 50 drops per minute, there is a progressive decrea to 300 drops per fluid oz.

Pocket radiation monitor. Philips Electrical Ltd., Centu House, Shaftesbury Avenue, London, W.C.2.

The Philips pocket battery monitor is intended for th location of radioactive ores and for the monitoring of radi tion in laboratories. The chief features of this instrume are claimed to be the combination of light weight (1 lb $9\frac{3}{4}$ o including batteries) and small dimensions ($6\frac{5}{8} \times 1\frac{5}{8} \times 4\frac{1}{8}$ in with adequate sensitivity. The batteries are enclosed in th body of the instrument so that the monitor can be carri in the pocket. A separate probe unit is not necessary becau of the small size of the unit. The Geiger tube indicat γ-radiations, β-particles of medium energy and X-rays. Tw ranges are provided, 0–40 counts/s and 0–800 counts/ corresponding with approximately 0–1·5 and 0–25 mr (radium γ-radiation). An earpiece can be connected for th audible detection of very low rates of count. The circuit arranged so that current is drawn from the batteries on when the counter tube actually registers counts. Th prolongs the life of the anode battery.

Miniature moving-coil relay. Electro Methods Ltd., Caxto Way, Stevenage, Herts.

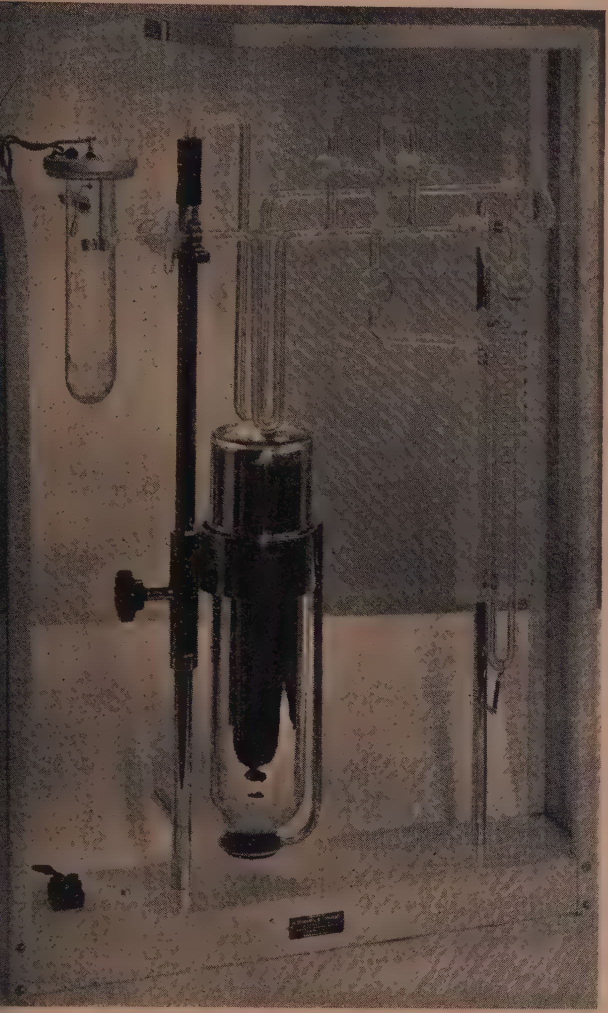
This miniature moving-coil relay consists of a balanc moving-coil in the field of a permanent magnet. The co has a contact leaf between two adjustable contact sprin mounted on the fixed frame. The coil assembly moves one side or the other and contact is made according to th direction of the controlling current. The coil has tw independent windings which can be wired in single, seri parallel or differential arrangements. The relay is ma netically self-shielded and operates from a power input 10 μW. Being of balanced construction, it functions in a position. The overall dimensions are $1\frac{3}{8} \times \frac{3}{4} \times \frac{5}{8}$ in. T platinum contacts can control a non-inductive load provid the power does not exceed 2 W or 100 mA at 50 V (a.c. or d.c The relay is supplied in two models, types 415 and 416, wi coils having resistances of 100 and 350 Ω respectively.

Apparatus for the determination of minute quantities of moistu W. Edwards and Co. (London) Ltd., Manor Roy Crawley, Sussex.

This apparatus for the determination of minute quantities moisture is made of hard glass with standard glass cone joi and is supported by a chromium-plated metal stand. T specimen container tube and lid are vacuum sealed by O-ring. An ampoule cutting and breaking device integ with the specimen container is provided for opening ampou under vacuum.

A specimen is placed in the container tube and a vacu pump connected to the system after isolating the manome incorporated in the apparatus. A refrigerated container then placed round the moisture trap. Water vapour fr the specimen during vacuum pumping is condensed as in the refrigerated moisture trap. The ice, after isolation the specimen and vacuum pump and the withdrawal of t refrigerated container, re-evaporates and causes a pressu rise in the system which is of known volume. The pressu rise is measured by a U-tube oil manometer calibrat directly in grammes of water. The makers state that t paratus will measure moisture contents as small as $\times 10^{-6}$ g.

For determinations which involve a larger volume of water pour than can be handled by the apparatus without the anometer fluid being forced out of the limb, the volume can



Apparatus for the determination of minute quantities of moisture

increased by making up a glass bulb of known capacity l attaching it on the B.14 cone provided. This, however, ails loss of sensitivity. To retain sensitivity, the apparatus used as previously but a series of readings are obtained, h within the capacity of the apparatus, until no more isture can be drawn from the specimen.

ernal brake motor. Dalmotor Co., Santa Clara, California, U.S.A.

e Dalmotor type PM-4 permanent magnet motor is intended applications calling for rapid stopping. The motor is ed at 40 W, 28 V d.c., and has a built-in magnetic brake ch dissipates the momentum of the armature in less than shaft revolution from the rated operating speed of 0 rev/min. The brake is spring actuated, being released a separate 28 V·d.c. circuit. The stalled torque is 50 oz/in. 0 A current and the dynamic brake torque is 100 oz/in. imum. The dimensions are approximately 2$\frac{15}{16}$ in. meter ×5¼ in. long, and the weight is 2·4 lb.

Bonded polytetrafluoroethylene. The Edison Swan Electric Co. Ltd., 155 Charing Cross Road, London, W.C.2.

Polytetrafluoroethylene (P.T.F.E.) is a resin-like substance with an unusually low coefficient of friction, it has toughness over a wide range of temperatures, has good insulating properties and is almost completely chemically inert. It may now be obtained bonded to metal or rubber, as bonded fibre–glass laminates, as continuous-length cylinders and as beakers for laboratory use.

Metallized polytetrafluoroethylene hermetic seal

Metal-backed P.T.F.E. may be fixed to a support by soldering or mechanical means and the makers claim that the adherence of the metal bond is such that satisfactory hermetic joints can be achieved. Laminates of P.T.F.E. bonded with rubber may be used as valve and pump diaphragms, washers, seals and flexible couplings. The makers state that the electrical and mechanical properties of the fibre-glass laminates remain unimpaired at extremes of temperature. The figure illustrates a metallized P.T.F.E. hermetic seal and a section showing metallizing. The metal is tinned for soldering.

Courtauld atomic models. Griffin and George Ltd., Ealing Road, Alperton, Wembley, Middlesex.

In the Courtauld atomic models, based on the designs of Hartley and Robinson,(1,2) the linking mechanism provides an elastically-distortable valency angle while maintaining the correct internuclear distance and allowing free rotation about a single bond. The distortable links extend the range of compounds which can be built, and give an indication of the degree of distortion produced by steric hindrance, if this occurs. The relatively long links give the models a greater degree of transparency than is obtained with other types of space-filling models, and if necessary the lengths of these links can be varied to give intermediate bond lengths. A separate atom model is required for each valency arrangement of an element, and certain groups of atoms, for example a benzene ring, are represented by single units. The scale of the models (which does not conform to The Institute of Physics' recommendations(3)) is 0·8 in. = 1 Å. The colour scheme also differs from these recommendations, but is claimed to be particularly suitable for black and white photographs.

(1) HARTLEY, G. S., and ROBINSON, C. *Trans Faraday Soc.*, **48**, p. 847 (1952).
(2) ROBINSON, C. *Disc. Faraday Soc.*, **16**, p. 125 (1954).
(3) The standardization of crystal structure models. *J. Sci. Instrum.*, **24**, p. 249 (1947).

Electronic recorder. Cambridge Instrument Co. Ltd., 13 Grosvenor Place, London, S.W.1.

In this electronic recorder, which is of the continuously balancing type, the rebalancing of the measuring circuit is effected by means of a small servomotor. Any voltage error due to unbalance is converted into a 50 c/s signal of appropriate phase and, after electronic amplification, is applied to the servomotor to drive it in such a direction as will restore balance. Damping of the recorder movement is obtained by feeding, to a suitable point in the amplifier, the voltage from a tachometer generator coupled to the servomotor. The recorder is operated from a.c. mains and the performance is stated to be practically independent of mains fluctuations. The 180 mm wide chart passes over a writing platen, enabling notes to be written on the record without removing the chart, the past 240 mm length of which can be seen through the window in the recorder door. The platen may be pulled forward to facilitate chart replacement, and this action automatically lifts the pen from the paper. For most applications, the instrument is supplied as a recording potentiometer for the measurement of small d.c. potentials, full-scale sensitivities down to 1 mV being possible provided the test circuit resistance does not exceed 300 Ω. The recorder will balance to about 0·1% of the scale length. It is critically damped, coming to rest without overshoot after a sudden full-scale change in the measured value in 2 s. The time to rest after a 1/10 scale change is less than ½ s. The slide wire is carried in an oil-filled container to minimize contact wear and is selected to be uniform to within 0·3% of its length, whilst an overall accuracy of 0·5% may be expected in normal circumstances. The slide wire current is normally obtained from an air depolarizer dry cell mounted in the instrument and is manually standardized against a Weston cell. This is stated to be satisfactory for most purposes, but where it is necessary to ensure standardization over long periods, the dry cell may be replaced by a mains-operated stabilized supply. The current from this unit is standardized as above and will thereafter remain constant to within about 0·1% for periods of a month or so. The recorder is available for single or multipoint recording. Single-point recorders use a syphon pen and provide a continuous line record. Multipoint records utilize a turret marker which picks up ink from reservoir pads and prints dots on the chart. Either 2, 3, 4 or 6 circuits are selected in turn by the recorder mechanism and the records are printed in different colours at the rate of 10 dots per minute. The recorders can operate at chart speeds from ½ in./h to 2 in./min.

An electrometric titrometer. Doran Instrument Co. Ltd., Stroud, Glos.

The dual titrometer is a continuously indicating instrument employing a step potentiometer in combination with an electrometer valve circuit. The titrometer comprises two complete titration assemblies with electric-motor stirrers, beakers and burettes, and permits the use of any electrode system in aqueous or non-aqueous solutions. The meter scale, in combination with a potentiometer, provides a range of +1·65 to −1·65 V, readable to 0·5 mV, and with a calomel glass electrode system a full pH range is available reading to 0·02 pH. The electrometer circuit is of the single-stage balanced input type. Large values of negative feedback have been used to ensure a stable circuit with minimum zero drift. All the direct-current voltages are obtained from a voltage divider maintained at constant potential by means of a neon stabilizing tube. The valves are a standard type and are under-run to give a long life.

The operating panel carries a twelve-point switch whic controls the potentiometer circuits for both millivolt an pH ranges. A second switch reverses the meter on millivo readings and also enables the circuit to be set for pH reading A third switch short circuits the electrode terminals for zer adjustment, connects a source of 250 mV for full-sca adjustment, makes provision for connecting in either th right- or left-hand side electrodes and allows the instrume to be standardized against an internal standard cell. Thr variable resistor controls are provided for adjusting th reading to zero, for full-scale adjustment and for compensatio of variations in asymmetry potential of individual gla electrodes.

Cathode-ray tubes with special afterglow characteristic Mullard Ltd., Century House, Shaftesbury Avenu London, W.C.2.

Cathode-ray tubes intended for short-range, navigation radar in estuaries and crowded shipping lanes should ha rather unusual screen characteristics. A screen with afte glow is needed for radar systems which display a map picture of the surrounding area. On the other hand, a afterglow of more than a few seconds cannot be tolerat because the picture of the sea at short ranges changes fair rapidly. To meet this requirement, a new range of rad display tubes has recently been introduced. These employ special grade of magnesium fluoride as phosphor. This h the property that it gives an intense afterglow lasting a fe seconds and then rapidly fades out.

Dielectric potentiometer. Technology Instrument Cor 531 Main St., Acton, Mass., U.S.A.

The type PD-2 dielectric potentiometer is a variable volta divider free of phase and frequency distortion over the ran 20 c/s to 10 Mc/s. The device is a three-terminal netwo The effective resistance-capacity shunt and series elements this network result from the resistivity and dielectric consta of a lossy liquid dielectric in which are immersed the termi structures. The output electrode can be moved relative the input electrode. Since the resistance and capacita components vary in exactly inverse manner with the mov ment of the output electrode, a constant *RC* product maintained in each of the ratio arms. The movement of t output electrode through the liquid dielectric provides smoothly continuous voltage division. The constant product of the two ratio arms assures the same volta division for all frequencies within the band range of t instrument. Similarly, there is no phase shift as the volta division ratio is changed. Attenuation range is approximat 25 dB. Input impedance over a wide range of values can provided on special order.

Pressure transmitter. George Kent Ltd., Luton, Beds.

With this pressure transmitter any normal pressure suction value can be measured and converted to an air sig which bears a linear relationship to the measured value. T types of measuring element can be fitted in the instrume For pressure ranges of 0 to 15 up to 0 to 2000 lb/in.^{2}, Bourdon tube is used; while for suction values, and press ranges of 0 to 3 up to 0 to 14 lb/in.^{2}, bellows units are us The measuring element is connected by a linkage to a K Mark 24 transmitter, which generates the air signal transmission to the receiving instrument. The transmit operates on a normal air-supply pressure of 17 lb/in.^{2}, wh is taken from the main air supply through a filter and combined relay pressure reducer.

Notes and comments

ward of the Duddell Medal

The 31st (1954) Duddell Medal has been awarded by The ysical Society to Professor A. C. B. Lovell who has, since 45, built up an important centre of radio astronomy. The drell Bank Experimental Station is perhaps best known for contributions to the study of meteors by radar methods. this field a number of entirely new methods of observations ve been developed; their application has produced evidence ich has, in the last few years, contributed much to meteor tronomy. The detailed survey of meteor-radiants carried t at Jodrell Bank led to the identification of intense day-time owers. The development of radio methods for determining e velocities of meteors has led to the study of the velocities the sporadic (non-shower) meteors, which has shown that negligible fraction of the incident meteors originates outside e solar system. Important contributions have also been ade to the study of the physics of meteor ionization, and the investigation of "winds" in the upper atmosphere by servations of persistant meteor trails.

In addition to these investigations of meteors, Professor ovell has been responsible for an important series of servations on the "scintillation" of radio galactic nebulae. ecently a new type of interferometer has been developed at drell Bank, and this has been used to measure the angular ameters of two of the intense radio stars.

e centenary of the birth of Sir Charles Vernon Boys

The Science Museum is commemorating the centenary of e birth of Sir Charles Vernon Boys by a special display instruments drawn from the permanent collections. V. Boys is regarded as one of the leading experimental ysicists of his day. His well-known work on the production d properties of exceedingly fine quartz fibres was associated ith his construction of a very sensitive radio-micrometer hich, aided by a reflecting telescope, was capable of detecting diation as feeble as that from the flame of a candle at a stance of almost three miles. The elastic properties of artz fibres were also utilized by Boys in designing a torsion lance with which he determined the Newtonian constant of avitation and the mean density of the earth with an accuracy eviously unattainable.

In addition to the original radio-micrometer and gravita- onal apparatus, the exhibits include Boys' lighting camera, s gas calorimeter and a number of mathematical instru- ents. The exhibition will remain open for a period of three onths from 15 March, the hundredth anniversary of Boys' rthday.

The Museum is open on weekdays from 10 a.m. to 6 p.m. d on Sundays from 2.30 p.m. to 6 p.m. Admission is ee.

remium for papers on instrument technology

A premium of thirty guineas is offered by the Australian ociety of Instrument Technology for the most outstanding per submitted to its Journal between June 1954 and the d of 1955. Further details may be obtained from the ociety, c/o F. O. Barnett and Co., 422 Collins Street, elbourne.

struments employing radio isotopes

The ever-growing field of uses for radio isotopes in industry w includes such items as the measurement of thickness, the checking of viscosity, package monitoring, the tracing of water leaks, the movement of silts and so on, in addition to their well-known uses in industrial radiography and in medicine. This has prompted the Scientific Instrument Manufacturers' Association of Great Britain Ltd., in association with the Atomic Energy Research Establishment, Harwell, to produce a 124-page illustrated catalogue of the products of some 40 firms. Its purpose is to assist the potential user of radioactive isotopes to select electronic equipment to suit his special needs. Details are given of the various detector-elements and associated apparatus used for radioactive assay and radiation monitoring, together with the names and addresses of manufacturers. In addition, information is given about the availability of special equipment for nuclear physics research, radio-chemistry, etc., as well as useful accessories, such as isotope containers, isotope handling apparatus, dry boxes, etc. Copies of the book may be obtained free of charge by *bona fide* enquirers from the Association at 20 Queen Anne Street, London, W.1.

Electronics exhibition

The Tenth Annual Exhibition organized by the Northern Division of The Institution of Electronics will be held at the College of Technology, Sackville Street, Manchester, 1, during the period 14–20 July, 1955. The exhibition will be open from 2 p.m. to 10 p.m. on 14 July, from 10 a.m. to 10 p.m. on 15, 18, 19 and 20 July and from 10 a.m. to 6 p.m. on 16 July.

Programmes of the lectures and film show (price 4½*d.*, post free) will be available in June and catalogues (price 2*s.*, post free) will be on sale early in July. Tickets are obtainable, free of charge, from the Honorary Exhibition Organizing Secretary, Mr. W. Birtwistle, 78 Shaw Road, Rochdale, Lancs., or from any of the exhibitors. A stamped and addressed envelope should be enclosed.

Conference on mass spectrometry

The Third Annual Conference on Mass Spectrometry under the sponsorship of American Society for Testing Materials will be held from 23 to 27 May, 1955, at the Mark Hopkins Hotel in San Francisco, California. The programme will consist of papers covering all aspects of the theory and application of mass spectrometry. Papers are invited and titles should be submitted by 15 February, 1955, to Mr. William Priestley, Jr., Standard Oil Development Co., Box 121, Linden, New Jersey, U.S.A.

An exhibition of mass spectrometry equipment will also be arranged and prospective exhibitors may obtain information from Dr. J. G. Hutton, General Electric Co., 1 River Road, Schenectady, New York, U.S.A.

Semiconducting materials and transistors—a bibliography

A thirty-eight-page bibliography has been produced of work on semiconducting materials and transistors which has been published over the past ten years. The entries have been classified into the following groups: semiconductors—theory and measurements; processing of semiconductors; transistors; new forms of transistors; rectifiers and diodes; other semiconducting devices.

This bibliography has been produced by the Research Department of W. G. Pye Ltd., Newmarket Road, Cambridge, from whom copies are available free of charge.

Noise Control

We have received a copy of the first issue of a new bi-monthly magazine called *Noise Control*. It is produced by The Acoustical Society of America and like the Society's *Journal* it is published for it by the American Institute of Physics (57 East 55th Street, New York 22, New York), from where details of the various subscription rates can be obtained. The magazine "is directed to the reader who needs to know about noise control—whether he is an engineer, the manager of a factory, an 'audiologist,' or an architect." The copy before us is produced in what we should call a characteristically American semi-popular style, with copious illustrations, some of a cartoon nature, and practically no mathematics.

The papers in this issue are: Fundamentals of noise control; What does the ASA "Z24-X-2 Report" mean?; Twenty-five years' research in outdoor noise; How quiet must it be to measure normal hearing?; Noise reduction of machinery and vehicles; Quieting of apartments and houses; Measurement techniques for special noise problems; Control of interior noise; A community's reaction to noise: can it be forecast? In addition there are sections entitled: Legal aspects of noise; They are doing something about noise; Books; Noise in the news; New products, and Letters to the Editor.

Proceedings of the Toronto Meteorological Conference, 1953

In September 1953 in Toronto some 200 meteorologists attended the first large-scale joint meeting of the American Meteorological Society and the Royal Meteorological Society. Their activities were arranged in the form of symposia on various branches of meteorology and the papers presented have now been published by the Royal Meteorological Society.

The subjects range widely in scale and application and include ozone distribution, arctic meteorology, climatic change, micrometeorology and cloud physics. To give some examples of individual contributions, one paper deals with the use of rocket soundings over New Mexico in studying ozone distribution up to a height of 70 km, while at the other end of the height scale there is a paper dealing with the investigation of the longer cores of material which can now be extracted from the sea bed in search of evidence of climatic change. Another paper considers the practical difficulties of setting up and maintaining weather stations in the arctic, while in yet another it is interesting to note that use has been made of aircraft exhaust trails in studying oscillatory and turbulent disturbances in the atmosphere. Finally, since no collection of papers on applied meteorology would be complete without some reference to atmospheric pollution, it is noteworthy that the present series contains one in which the bearings of pollution on climate and health are discussed.

The papers mentioned are but a few of about fifty interesting and stimulating papers in this volume which provide a valuable record of the present progress and trends in the broad field of meteorological science.

The volume can be obtained from the Royal Meteorologic Society, 49 Cromwell Road, London, S.W.7, price 3 (including postage).

New international barometer conventions

The publication of B.S. 2520: 1954 *Barometer conventio and tables* is noteworthy for the specification of a simplifi system of barometer conventions which has received stro support both in this country and internationally (see *Natur* 18 Dec., 1954, **174**, p. 1127, and *D.S.I.R. Notes on Appli Science No.* 9, *Measurement of pressure with the mercu barometer*. London: H.M. Stationery Office, 1955). includes, in the simplest form, the approved pressure uni for use for all barometric purposes, and the standard instr mental conditions for mercury barometers.

The new system eliminates the sources of confusion ar error hitherto associated with the measurement of pressu by means of the mercury barometer, by adopting 0° C ar the conventional value $980\cdot665\ \mathrm{cm/s^2}$ for standard gravit not only in the definitions of the millimetre and inch mercury pressure units, but also in the standard instrument conditions associated with all scales, including those altitude, on mercury barometers. Scale-readings on mercury barometer will thus, for the first time, show the sam interrelationships as those on an aneroid and those betwee the units employed. The instrumental conventions f millimetre barometers are unaltered, but certain changes, which the standard gives full details, apply to millibar ar inch barometers. The standard also incorporates temperatu and gravity correction tables applicable, under the new co ventions, to Fortin and Kew barometers of all patterns.

Scientists, including teachers of science, can do much further the general adoption of this new standard by e pressing barometric pressures exclusively in terms of th recognized units, and by bringing existing millibar and ind barometers into accord with the new conventions at the fir opportunity.

British Journal of Applied Physics

Contents of the May issue

ORIGINAL CONTRIBUTIONS

The solution of plane stress problems by an electrical analogue method. By Liebmann.

The resistivity of thin metallic films. By D. E. Clark.

Desorption of gas in the cold cathode ionization gauge. By E. Brown and J. Leck.

The rheology of Portland cement pastes. By G. H. Tattersall.

X-ray emission spectroscopy with electron excitation covering elements $_4$Be–$_{92}$ By G. L. Macdonald and M. G. Harwood.

A two-state light activated circuit element using germanium. By J. W. Granvil

An analogue study of the temperature distribution in cooled gas-turbine blad By C. F. Kettleborough.

The orientation of fibres in an electric field. By J. O. Isard.

NOTES AND NEWS

Correspondence

The study of semiconductor crystal perfection by X-ray diffraction metho From P. J. Holmes.

A simple and rapid method of measuring the complex permittivity of a liqui From E. H. Grant.

The thermal conductivity of some technical materials at low temperatures. Fro R. Berman, E. L. Foster, H. M. Rosenberg.

New books Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principles, construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Square, London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation of contributions*. (Price 2*s*. 6*d*. including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon application from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, London, E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within 60 days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of address or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £4 per volume ($11.50 U.S.A.), including index (post paid) payable in advance. Single parts, so far as available, may be purchased at 8*s*. each ($1.15 U.S.A.), post paid, cash with order. Orders should be sent to The Institute of Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

Precision measurement of time*

By H. M. Smith, B.Sc., M.I.E.E., F.Inst.P., Royal Greenwich Observatory, Abinger Common, Dorking, Surrey

The fundamental standard of time is made available by means of radio time signals controlled from an observatory. Local time standards may be in the form of chronometers, pendulum clocks or, often more conveniently, quartz crystal clocks. Various forms of chronograph are available enabling events to be recorded in terms of the time scale provided by the local standard. Drum and tape chronographs are simple, robust and of adequate accuracy for many purposes: printing and photographic chronographs possess the advantage of eliminating the need for measurement. Despite the disadvantages involved in employing photographic processes, this form of timing has been found advantageous in, for example, the photographic zenith tube telescope. Interval timers, employing the charge or discharge characteristics of a condenser, are available in convenient portable forms. Specialized cameras have been designed for timing field and track events, and may well find applications in scientific work. An accurate chronograph using a Kerr cell is also described. Decimal counter chronometers are available in various forms, some of which employ cold-cathode tubes. Brief reference is made to oscillographic methods of timing, and two examples are quoted from the work of the Royal Observatory. The review closes with some comments on the present proposals for a new definition of the unit of time.

ll physical measurements are based ultimately upon the ree fundamental quantities, length, mass and time, xpressed in terms of units which have been adopted by ternational agreement. In the case of length and mass, as the case of many of the derived quantities, there are in xistence material primary standards with which individual ational standards may be compared. In the case of time, a ifferent procedure must be adopted: the unit of time must e defined in terms of some regularly recurring natural henomenon, capable of being measured at suitably-equipped nstitutions in the different countries of the world. Moreover, e determination of time and the intercomparison between e time standards adopted in the various countries must be continuous process. It is not, and may never be, possible o construct an artificial standard capable of providing a cale of time comparable in uniformity and permanence with ertain natural phenomena.

From the earliest times the activities of man have been egulated by the alternation of light and darkness, and even efore it was known that the Earth rotated on its axis, the pparent passage of the Sun across the sky served to mark ff the passage of time into convenient units. In fact the econd, the modern unit of time, is still legally defined as a articular fraction of the day, measured by the period of otation of the Earth on its axis. Recent investigations of lanetary motions have, however, revealed that the rotation f the Earth is not uniform, but suffers irregular and unpredictable changes. This has led to the consideration of a ew definition of time based upon the revolution of the arth around the Sun, that is, upon the year and not upon e day. The new time scale, designated "Ephemeris time," recommended for use in all cases where the mean solar econd is unsatisfactory as a unit of time by reason of its ariability.

RADIO TIME SIGNALS

For practical purposes the standard of time takes the form f radio time signals controlled by the major national observatories, and provides a time scale of adequate uniformity or general use in scientific work. The Royal Greenwich bservatory is the time-keeping authority for this country, and maintains a regular service of time signals transmitted from the Post Office radio station at Rugby: these provide a high-precision service giving a reasonable measure of world coverage. Other time signals are sent by land-line to the British Broadcasting Corporation and are radiated on the normal home and overseas services.

The highest precision in the radio time signals is demanded mainly for the standardization of time interval: absolute time is required with great accuracy only in intercomparisons between observatories and in major surveying projects. In physical laboratories, for example, precise timing is often required to determine the length of time over which certain conditions are operative in an experiment or test: in other cases attention is directed to the variation of some quantity per unit time interval. Such experiments may conveniently be timed by means of a local clock whose rate is determined by comparison with the radio time signals.

Frequency standardization is intimately linked with time determination. For most practical purposes it is convenient to calibrate a local frequency standard in terms of one of the standard frequency transmissions now available. The frequency of the oscillator controlling the standard frequency transmission must of course be expressed as the number of cycles occurring in the standard unit of time. Thus the time service of the Royal Greenwich Observatory provides the uniform time scale in terms of which the National Physical Laboratory calibrates the frequency standards employed for the control of the British standard frequency transmissions. In some other institutions where frequency standards of the highest precision are maintained, comparisons with standard frequency transmissions are supplemented by direct calibration in terms of the observatory time standards.

The international time signals from this country are radiated at 1000 and 1800 daily by the Post Office transmitter GBR on a frequency of 16 kc/s, and serve local as well as distant areas. Supplementary transmissions are made from selected short-wave stations, the frequencies of which are chosen with regard to prevailing ionospheric conditions. Owing to the slow build-up time of the signal dots of the 16 kc/s transmission, it is necessary to ensure that measurements are always made at the same point of the build-up curve. For monitoring purposes at the observatory, the reference point adopted is that at which the signal reaches 40% of its maximum value. In the case of the short-wave signals this difficulty does not arise, but the ultimate accuracy obtainable is adversely affected by uncertainities in the propagation time.

---

* Based on a lecture arranged jointly by The Institute of Physics nd the Department of Extra-Mural Studies of the University of ondon and delivered on 31 January, 1955.

LOCAL TIME STANDARDS

It is seldom practicable to employ the radio time signals directly during the course of the experiment or test, and it is usually far more convenient to use a local standard as a source of suitable timing pulses. A good quality pendulum clock properly mounted in a permanent location can usually be relied on to maintain a stability of rate within a few tenths of a second per day. A similar stability may now be achieved by means of a simple quartz clock which may well compare favourably in initial cost. Moreover, the quartz clock can be made to provide timing pulses subdividing the second into convenient decimal parts, such as thousandths, hundred-thousandths and even millionths. In situations where a less complex and expensive equipment is required, and where a somewhat lower standard of accuracy will suffice, it may be advantageous to use a valve-maintained tuning fork instead of a quartz crystal as the controlling element of the clock. The marine chronometer is still employed when portability and reliability are the over-riding considerations, but robust portable quartz clocks of low power consumption have been designed and constructed, and may well displace the chronometer in the near future. It may be remarked that the high precision of the modern watch, combined with its unsurpassed convenience, will no doubt lead to its being retained for many years for timing purposes within its own particular field of utility.

The need sometimes arises for carrying out time measurements at the maximum accuracy obtainable. This necessitates the employment of a quartz clock of the highest possible precision which will run for long periods so that its performance may be assessed in terms of the radio time signals over long intervals of time. It is at this stage that it becomes necessary to apply to the radio time signals the corrections published by the Royal Greenwich Observatory in the *Time Service Bulletin*. During the war years 1939–45 the British Post Office produced a considerable number of high-precision quartz clocks employing GT-cut plate crystals* in a bridge circuit. The next stage was the adaptation of the bridge circuit for use with Z-cut Essen ring crystals,† and clocks of this type are now employed as primary standards at the observatory and at various establishments co-operating in the Greenwich Time Service.(1) Within the last decade high-precision quartz frequency standards have also become available commercially: when used as clocks they are capable of a long-period stability of rate better than one millisecond per day. An interesting drive circuit has recently been developed in which a servo-system is employed to obtain a phase-balance and to counteract the effects of any changes in the maintaining circuit.(2) Information on the quartz clocks of Post Office design has now been made available, and it is understood that a commercial version may be in production in the near future.

Experience has shown the value of employing primary quartz clocks in groups of three, and of making continuous intercomparisons between the three oscillators of the group. In this way, any departure from uniformity of a single oscillator can be easily detected, and there is adequate information for bridging the interruptions arising from stoppages, whether accidental or deliberate (for the purposes of readjustment). It is desirable that arrangements shou be made to ensure continuity of power supplies to the mai taining amplifiers and to the crystal temperature contr circuits. Accurate seconds pulses may be convenien obtained by electronic division, but two divider chains, o main and one reserve, are sufficient for a group in which t continuous intercomparisons at the crystal frequency a made by rotary beat counters or some similar integrati devices.

CHRONOGRAPHS

Despite the increasing use of electronic equipment, the are many timing problems which may be satisfactorily solv by the employment of simple chronographs in which pe deflected by electrical impulses mark a permanent trace on uniformly moving paper tape or sheet. In the drum chron graph the sheet is wrapped around a cylinder which is rotat at a constant speed. The pens are carried along the leng of the drum by a lead screw, and thus mark helical traces the paper. Usually one pen is deflected by the secon impulses from the standard clock, while the other is operat by the pulses whose time is to be determined. This type chronograph has the advantage that a large number records, extending perhaps over many hours, may be record on a single sheet of paper, with resulting convenience reading and storing. The accuracy attainable is limited the inertia and friction associated with the pen movemen and by the precision with which the trace may be measure Thus the modern drum chronograph often employs a lig stylus which scribes a thin line on a coloured paper thin coated with wax: it may be arranged that the stylus on makes contact with the paper when deflected. In a typic example (of French manufacture) the drum, which is 50 c long and 50 cm in circumference, is rotated at one revoluti per second, the constancy of the speed being controlled by 1000 c/s current derived from an external quartz clock. T accuracy is of the order of 0·2 ms.

The tape chronograph is more suitable in cases where portable instrument is required. In the models used at t Royal Greenwich Observatory, the paper tape, $\frac{5}{8}$ in. wic is drawn through the instrument at a uniform speed by electric motor. The two pens, which are electromagnetica operated, are made of silver tube of 0·2 mm internal di meter. Commercially available red ink, filtered to remo any solid residue, is suitable for use with these pens, provid that a small amount of glycerine is added, together with little formaldehyde to inhibit fungoid growth. Such chron graphs are in regular use in some of the telescope domes the observatory, and have also been employed on eclip expeditions abroad. They are robust and reliable: accidental errors for single readings are about 1/100 s (10 m but systematic errors are small, and the timing accuracy materially improved if it is possible to take the mean o series of measurements.

If a large quantity of chronographic records is involv the task of measurement becomes considerable, and a dema thus arises for a chronograph giving a printed record of times of the observed pulses. A timing accuracy of one mi second is attained in an instrument which is commercia available, but because of the time occupied by the printi operation, it is unable to record pulses separated by mu less than one second.(3)

The same accuracy may be achieved by employing pho graphic techniques in an instrument which is less comp electrically and mechanically. A quartz-controlled pho motor drives, at one revolution per second, a shaft carry ransparent disk. Figures indicating hundredths of seconds e marked near the edge of the disk. An adjacent disk, ared to rotate at one revolution per minute carries seconds visions. The passage of the figures on the disks past the e joining their centres provides a continuous indication of ne, in seconds (from the 1 rev/min disk) and decimals of a cond (from the 1 rev/s disk). An argon flash-lamp is aced in front of the disks and, when triggered by a signal lse, throws a brief shadow-picture of the time-indication to a strip of bromide paper contained in a simple camera hind the disks. After each flash, the photographic paper moved on 0·2 in. by an impulse motor. The resulting cord gives the time of each flash, the seconds and hundredths pearing as numbers on the strip, and the thousandths being timated by interpolation to one-fifth of a division in lation to a fixed fiducial mark. The apparatus is simple, t its employment does involve photographic processing, beit of an elementary nature. In the field of time measure-ent, all photographic methods suffer from the disadvantages at:

---

* MASON, W. P. *Proc. Inst. Radio Engrs*, **28**, p. 220 (1940).

† ESSEN, L. *Proc. Phys. Soc.* [*London*], **50**, p. 413 (1938).

(1) the result of measurement is not immediately available;
(2) it may not be apparent until after the record has been developed that some fault in the equipment has rendered the whole series of measurements useless;
(3) there is always a risk, however slight, that the record may be irretrievably lost during handling and processing, and
(4) if any considerable quantity of records is involved the photographic processing (together with mixing of chemicals and cleaning of utensils) may become onerous.

An interesting example of a photographic chronograph is corporated in the photographic zenith tube telescope now course of erection at the Royal Greenwich Observatory at erstmonceux. It is necessary to record, with an accuracy one millisecond, the motion of a carriage carrying the ellar photographic plate which moves approximately 3 mm 20 s. It was anticipated that difficulties would arise in aking the carriage operate contacts to give timing pulses the required accuracy. The method adopted has been to cord, on a subsidiary fixed photographic plate, a series of nall images of a pin-hole moving with the carriage and uminated by a flashing lamp controlled by the standard ock. The lamp flashes every 2 s, and the optical system troduces a magnification factor of five so that the record nsists of a series of dots spaced about 1½ mm apart. After evelopment, the plate is measured in a high-grade measuring achine.

There are now available a number of lamps capable of roviding a light flash of high intensity and very brief duration. recise timing measurements of repetitive events may often carried out by means of a stroboscopic arrangement in hich a uniformly rotating disk or drum is illuminated by a mp of this type. Although inherently simple in principle d construction, it has not been very widely employed, ssibly because of competition from electronic devices of eater versatility.

Interval timers of moderate accuracy have been constructed a small and easily portable form, utilizing the charge or scharge characteristics of a condenser. In a typical instru-ent a condenser and series resistance are connected across a V battery; initially the condenser is short-circuited by a itch which is opened at the commencement of the interval be timed. At the completion of the interval a second itch isolates the condenser from the charging circuit. The voltage attained by the condenser, which is a known function of the charging time, is measured on a decade potentiometer. Various ranges are provided from 5 ms to 1000 ms. The instrument is self-contained and portable, power being obtained from dry batteries. The accuracy, which is limited chiefly by dielectric absorption in the condenser and by leakage in the components, is of the order of 0·5 ms on short intervals, or 0·5% on long intervals.⁽⁴⁾

There is a particular sphere of activity in which precise timing of a rather specialized nature is required. In the timing of track and field events it is necessary to determine the order of arrival of the various competitors at the finishing line and the individual times, particularly when these are to be compared with existing local, national, or international records. In response to this demand, efficient portable timing equipment is commercially available which produces a photographic record of the individual competitors at the instant that each one crosses the finishing line; the same film also carries a time scale from which the individual times may be determined (see Fig. 1). It is clear that the required information cannot be obtained from an instantaneous snapshot of the competitors, taken at the instant when the first one reaches the finishing line, since this cannot give the times of the other competitors, and may not give the true order of finishing. The camera field is restricted to a narrow line which is optically aligned with the finishing posts, and the film is moved at right angles to this line at a uniform speed corresponding to the anticipated speed of the competitors. The result is a composite photograph showing in time sequence the passage of the competitors across the finishing line. As the legs of the competitors, for example, will not be travelling at the anticipated average speed of the competitors, they may appear distorted in the photograph. This is of slight importance, since it is customary to time competitors in relation to a selected part of the body or head, such as the chest of an athlete, or the nose of a horse. One feature of the equipment is that the photograph is available for examination and measurement in a matter of only about one and a half minutes. Although the primary purpose for which the instrument was designed appears to have little direct connexion with laboratory work, it may well prove of value in certain scientific investigations involving precise timing.

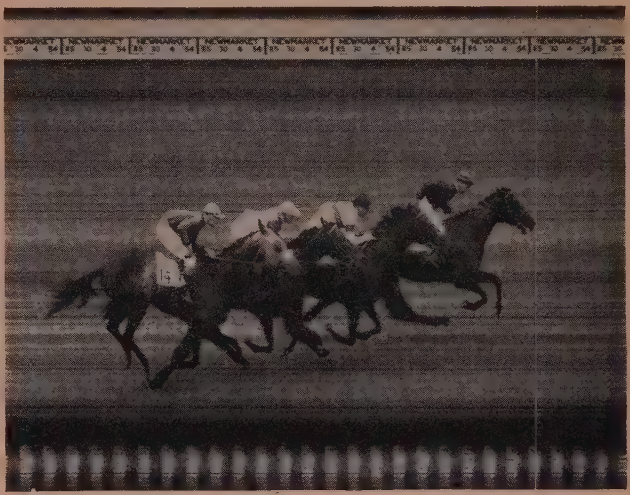


Fig. 1. Typical record obtained with Racend Omega timer

An ingenious photographic chronograph has been developed for applications in which an accuracy of better than one microsecond is required. Instead of employing a mechanical method of switching or interrupting the incident light beam, the chronograph controls the trace obtained on the film by using the well-known properties of polarized light. A slightly converging beam of light passes through a polarizer, followed by a Kerr cell containing nitrobenzene [see Fig. 2(*a*)]. The light emerging from the Kerr cell passes through an analyser, and is focused on a recording film. The arrangement is such that the cell is rapidly discharged, and the light is suddenly extinguished. In the chronograph as described there are two such independent signal traces, lying either side of a time-scale. Timing marks at intervals of 10 ms are provided by means of an independent device in the centre of the polarized beam [see Fig. 2(*b*)]. A quartz crystal, oscillating at 50 kc/s, has a small central window through which the light can pass. A compensator is arranged so that passage of the polarized beam occurs only at the extremities of the quartz vibration, i.e. 100000 times per second. Additional timing pulses at intervals of 100 ms are obtained by means of auxiliary electrodes in the Kerr cell, which receive electrical pulses at one-fifth of the crystal frequency. A limit to the precision is set by the time taken (10^{-9} s) for the liquid in the Kerr cell to alter its optical properties in response to the application or removal of the electric field. The electrodes of the cell form a condenser: in practice this is charged through a resistance which limits the rate of voltage rise, and destroys the sharpness of the recorded signal. Discharge of the condenser is by means of a direct low-resistance short-circuit, and provides a sharply-defined edge on the photographic trace. By using the operating signals to discharge the tw outer electrodes of the cell in succession, time intervals ma be determined with a precision of the order of 0·1 ms.(5)

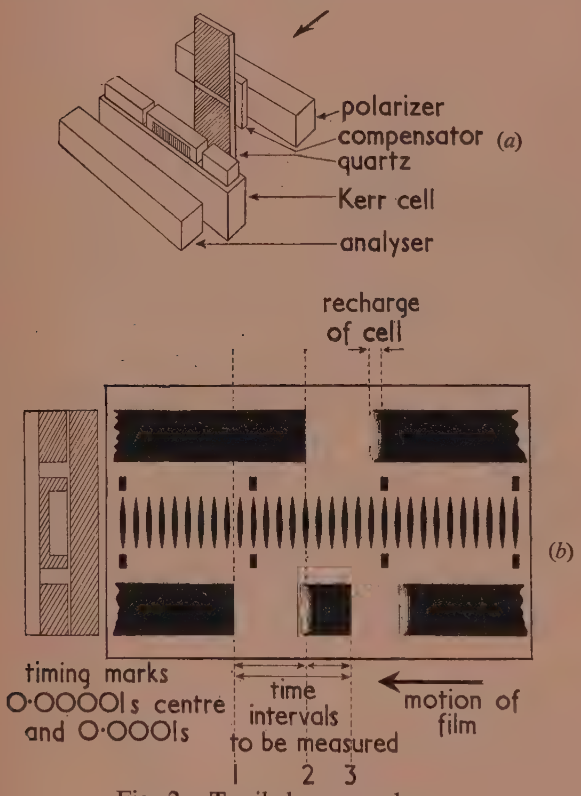


Fig. 2. Tawil chronograph

(*a*) Schematic diagram.
(*b*) Form of record obtained.

COUNTERS

A particularly valuable feature of a clock which has, its controlling element, a crystal or fork vibrating man times per second is that time intervals may be measure directly by counting the number of oscillations occurrin between the commencement and ending of the interval co cerned. A typical modern quartz clock has as its controllin element a quartz crystal oscillating at 100 kc/s which, conjunction with a suitable counting unit, permits a timin accuracy of 0·00001 s. In fact, circuits have been develope which are capable of counting at this rate, and which may started and stopped by appropriate signal pulses. Th decimal counter chronometers working on this principle we first introduced into the work of the Royal Greenwic Observatory over ten years ago. At the completion of eac count the elapsed time interval is indicated on a series of fi decade dials. The "start" signal is provided by a secon pulse from one of the standard clocks, and the "stop" sign from a received radio time signal or another clock which is be compared with the first standard clock. Cases ofte arise in which it is required to determine the mean value of series of measures of nominally equal intervals, subject small individual variations arising from accidental scatte The individual readings may be combined in the decim counter chronometer so that the dials give the accumulat sum of ten successive intervals, which represents the mea value to an additional decimal place. For the measureme of longer intervals without the necessity of providing add tional dials and counter units, a lower count frequency ma be employed, with, of course, a corresponding reduction accuracy. In the counters used at the Royal Greenwi Observatory, a switch has been fitted to permit the selectic of the appropriate count frequency for the measureme being made. For some applications a timing accuracy better than 0·00001 s is required, and counters have bee developed capable of operating on count frequencies 1 Mc/s and 10 Mc/s.

In some early decimal counter chronometers, the countin units were somewhat complex and difficult to maintain: ev the modern counter uses a considerable number of thermion valves, and thus tends to be bulky and to require a fair large power unit. Consideration has accordingly been giv to the design of decimal counters employing cold-catho tubes. There are some cold-cathode tubes, such as t Dekatron, which form a complete decade counting unit a at the same time provide a visual indication of the count. These have proved especially useful in small portable counte operating on a count frequency of 1 kc/s, but the types no available are not recommended for use at count frequenci higher than 20 kc/s. There is, however, available an electr beam tube which also forms a self-contained decade u with visual indication, and which may be used at cou frequencies up to 100 kc/s, or even higher.(7) An alternati tube capable of counting to high frequencies, known as t Trochotron, is now coming into use.(8)

The measurement of time intervals by counting techniqu may be extended not only in the direction of microsecon but also to minutes, hours and days. Recent work at t Post Office has resulted in the development of a clock whi carries out a pre-determined cycle of switching operatio each day.(9) In a cold-cathode trigger-tube clock at t yal Greenwich Observatory, seconds impulses from a katron divider are counted in successive rings of 5, 3 and ubes to give minute pulses: in further similar rings to give ur pulses: then in rings of 2, 4 and 3 tubes to give daily lses. Appropriate tubes in the various rings are con- cted to switching tubes in such a way as to synthesize the rious time signals which are normally controlled from the servatory.

OSCILLOGRAPHIC METHODS

The widespread knowledge of cathode-ray oscillograph chniques, combined with the versatility of the modern rtable instrument, has led to the development of a multitude timing methods applicable to many different problems. particular, the rapid measurement of short time intervals ade very great progress in the war-time development of dar. The types of oscillograph display were chosen to eet the special requirements of certain operational equip- ent, but the general principles involved are capable of der application, and may often be used directly or in a odified form in general problems of precise time measure- ent. There is an extensive literature available, and it is early outside the scope of this article to attempt an exhaustive rvey, or even a classification of the methods which have en made known.(10,11) It may, however, be of interest to ote, as typical examples, two oscillographic methods hich have been found useful in recent work at the Royal reenwich Observatory.

Reference has already been made to the slow build-up of e time signal dots radiated from a long-wave transmitter. or precise measurement it is essential to determine the form the build-up curve, to choose a convenient reference-point r measurement, and finally to determine the time by the cal clock at which this reference-point is reached. It ould, of course, be possible to apply the received radio time gnal as a vertical deflexion, and record the trace on a film oving horizontally; but interest is centred exclusively on the ms or so of the build-up, and the signal dots are 1 s apart. order that the form of the build-up should be clearly splayed, a fairly high film speed is necessary, which results a high consumption of film, of which some 99·2% contains useful information. The method employed, therefore, is draw out the picture by a horizontal time-base, and to otograph each picture on a film moving vertically in steps tween signal dots. The trace is suppressed until shortly fore the signal dot is due to commence, so that the film cord contains only the wanted information. Precise timing afforded by modulation of the oscillograph beam intensity: e trace consists of a series of dots at intervals of 0·1 ms, th identification signals marking the milliseconds.

In the case of short-wave time signals, the build-up of the diated dot is rapid and well defined, but liable to con- derable distortion in propagation. For example, the conds dots superimposed on the WWV standard frequency ansmissions consist of five cycles of 1 kc/s modulation, it as received in this country, the signals may be distorted, e form of distortion often changing from one dot to the xt. It is therefore of considerable advantage to display e incoming signals on a cathode-ray oscillograph, and to ake time measurements on the average of those signals hich have suffered the least distortion. The incoming radio gnal is applied as a vertical deflexion, and an applied orizontal time-base draws out a picture of the signal wave- rm. The transmitted dots are accurately spaced at seconds tervals, and if the traverse of the time-base is initiated by the seconds signals from a local source, successive dots would, if undistorted, appear perfectly superimposed on the oscillograph screen. For each dot, the time-base performs a single traverse of 15 ms duration: the beam is then suppressed for the remainder of the second. A timing comb is provided by a second beam which is deflected horizontally in synchronism with the first beam and scaled by vertical marks derived from short, sharp pulses at 1 ms intervals (see Fig. 3). In each second, the first of these timing pulses triggers the time-base, and constitutes a reference signal for measurement.

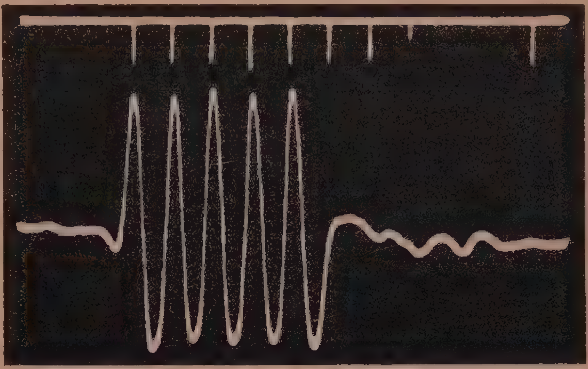


Fig. 3. Measurement of time signals by visual oscillographic method

Top trace: Millisecond markers (Nos. 0, 1, 2 suppressed; No. 10, half-amplitude).
Lower trace: WWV 15 Mc/s time signal—(5 cycles of 1000 c/s).
The time signal may be advanced or retarded until the peaks coincide with the millisecond markers.

It may be advanced or retarded by a phasing device, thus enabling the displayed time signal dot to be traversed and brought into coincidence with a selected millisecond marker. Because of the inevitable scatter of the signals, the dots may appear slightly to the left or right of the mean position; it is thus inconvenient to aline the signal with the initiating time marker at the extreme left of the display. It was found convenient to utilize the marker occurring 3 ms after the initiating pulse, and to avoid confusion, the two intervening markers were suppressed. In practice, the procedure was simplified by the use of a long after-glow tube, which assisted the observer in locating the mean of successive signals; seriously distorted signals could be clearly distinguished, and automatically rejected. The required result could be readily obtained by noting the setting of the phasing adjustment, and applying the 3 ms correction. Check measures were made by comparing the initiating pulses with the signals of a standard clock by means of a decimal counter chronometer. The accuracy achieved by the method compares favourably with that attained by various well-known photographic methods, and entails far less work.

THE UNIT OF TIME

The details of the processes by which the fundamental determination of time is effected by an astronomical observatory have not been considered in this account: a general description of the methods currently employed is available elsewhere.(12) It is, however, relevant to refer briefly to an impending change in the definition of the unit of time. When this is adopted, it will involve timekeeping observatories in regular observations of a different type from those normally used for time determination and in a fundamentally different procedure in establishing a uniform time system. There will also be far-reaching implications in other branches of scientific work since the new unit of time will differ from the old unit by an amount which will be significant in such applications as precise frequency standardization.

As has been mentioned earlier, the second, as at present defined, is not an invariable unit, and the fluctuations in its length have become an increasing embarrassment. A further difficulty arises in that the definition of mean solar time was framed before some of the present sources of irregularity were fully understood, with the result that it has been variously interpreted, and there is now some divergence in practice between the methods adopted at the various observatories in the establishment of a practical time system. The broad general principles of the definition of the new unit have been agreed, but there are a number of practical difficulties to be overcome before the new time system can be made generally available. One of the major problems to be solved arises from the fact that the astronomical observations concerned are at present subject to a considerable accidental error, and must therefore be smoothed over long periods. The standard quartz clocks at present available are subject to slight random variations in drift which render them inadequate over the long periods involved, but if it were possible to check the drift independently, the quartz clock could be satisfactorily employed. Developments now in progress in the U.S.A. and in the U.K. in the realization of a frequency standard stabilized by atomic or molecular phenomena offer a promising solution of this problem. It would then be possible to employ the atomic or molecular frequency standards to give a quantitative indication of any departures of the quartz clocks from a constant frequency. The application appropriate corrections makes available a clock of effective uniform frequency, i.e. uniform rate, which may then directly compared with astronomical observations of t fundamental time standard.

REFERENCES

(1) Smith, H. M. *Monthly Not. Roy. Astron. Soc.*, **11** p. 67 (1953).
(2) Lea, N. *Marconi Rev.*, **17**, p. 65 (1954).
(3) Masson, G. *Ann. Franç. Chronom.*, 2^{e} série, 20^{e} anné p. 275 (1950).
(4) Spilsbury, R. S. J., and Felton, A. *J. Instn Ele Engrs*, **94**, Pt. II, p. 316 (1947).
(5) Tawil, E. P. *Ann. Franç. Chronom.*, 2^{e} série, 20^{e} anné p. 69 (1950).
(6) Bacon, R. C., and Pollard, J. R. *Electronic Engng*, **2** p. 173 (1950).
(7) Van Overbeek, A. J. W. M., Jonker, J. L. H., an Rodenhuis, K. *Philips Tech. Rev.*, **14**, p. 313 (195
(8) Kuchinsky, S. Multi-output beam switching tubes f computers and general purpose use. *Conventi Record of the Institute of Radio Engineers*, Part p. 43 (1953).
(9) Dobbie, A. K. *Post Off. Elect. Engrs' J.*, **48**, (I), p. (1955).
(10) Chance, B., Hulsizer, R. I., MacNichol, E. F., an Williams, F. C. *Electronic Time Measurements* (Ne York: McGraw-Hill Book Co. Inc., 1949).
(11) Proceedings of the Radiolocation Convention. *J. Ins Elect. Engrs*, **93**, Pt. IIIA (1946).
(12) Smith, H. M. *Proc. Instn Elect. Engrs*, **98**, Pt. II, p. 1 (1951).

centrifuge permitting continuous observation of the spinning tube

By B. B. Marsh, M.Sc., Ph.D., Dominion Laboratory, Department of Scientific and Industrial Research, Wellington, New Zealand

[*Paper received* 19 *January*, 1955]

A description is given of a few simple modifications to a centrifuge to allow the observation of a spinning tube. The volumes of the separate phases within the tube can be read directly and continuously during centrifugation.

an earlier paper dealing with certain aspects of the bio- emistry of muscle, a brief description was given of an paratus permitting continuous observation of the volume the solid phase of a muscle homogenate during centri- gation.* Definition and ease of observation have been proved by recent modification of the original design, and possible application in other fields of research has been ggested. This paper describes the few changes required convert a laboratory centrifuge to this type, and offers an planation of the observed effects.

DESCRIPTION AND OPERATION

Two restrictions govern the choice of centrifuge in this work: head must be available to accommodate a graduated 10 15 ml. tube in the "swing-out" position, and the design ıst permit the addition of a light source in the base of the sing at a point vertically below the path of the out-swung be. The centrifuge size 1 type SB (by International Equip- ent Co., Boston, U.S.A.) has proved satisfactory in these spects, a light placed vertically below the drainage hole in e floor of the casing being in the correct position. Definition much improved if the hole is reduced in size to a radial slit, × 1 mm, and eye fatigue is lessened if a small shield, × 2 mm, is mounted about 5 cm vertically above and in e with the slit to prevent direct light from reaching the eye. nce the images to be described appear on either side of the ht source, the shield does not restrict observations while minating the main cause of eye-strain. The shield and slit n be fitted conveniently into one unit if a 5 cm length of be is mounted vertically through the hole in the floor of the casing; the lower end is blocked except for the slit while the upper end is open apart from the shield.

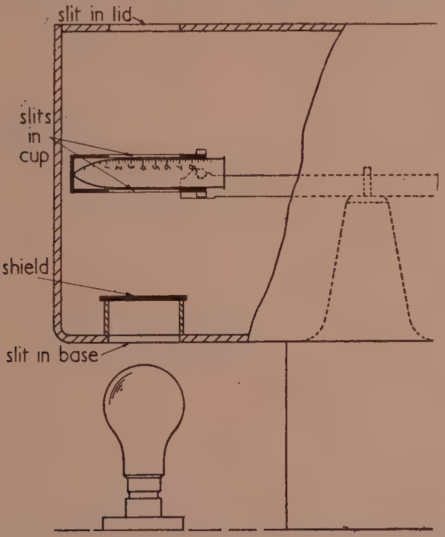
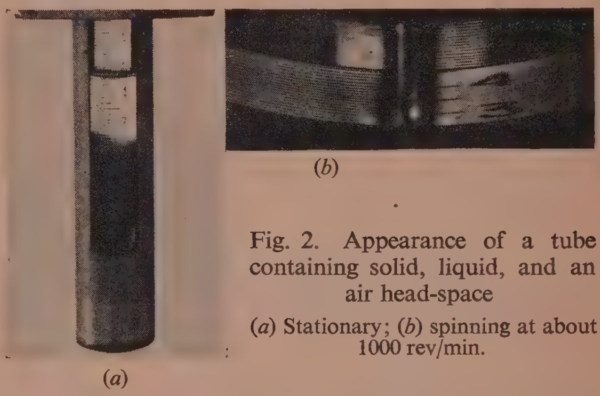


Fig. 1. Diagram showing the relative positions of lamp, slits and shield

Diametrically opposite each other in the wall of a metal centrifuge cup are cut two slits, 5 × 1 cm, the greater dimension being in line with the axis of the cup. The cup is placed in such a position that once during each revolution the two slits, the light source, and the shield are vertically in line. To complete the apparatus a viewing slit about 5 × 0·5 cm is cut in the lid of the machine vertically above and parallel to the slit in the casing floor.

The relative positions of centrifuge tube, light source, shield and slits in the casing are shown in Fig. 1. It should be noted, however, that these modifications merely improve definition; the effect is observed, though less clearly, when a circular light source of 5 cm diameter is used without shield, centrifuge lid, or metal cup, the glass tube being suspended directly in the trunnion ring.

When a graduated centrifuge tube containing both liquid and solid is spun in this apparatus, an effect is observed similar to that shown in Fig. 2, a time exposure made while the centrifuge operated at about 1000 rev/min. While no light passes through the solid layer (2·6 ml.), the zone of light transmitted by the liquid-filled portion of the tube contains images of the graduation lines and numbers etched on the tube. The volume of the solid phase is thus easily read by reference to the lowest visible graduation line, and may be observed continuously during centrifuging. In the air head-space the images of the numbers are reversed and appear on the left of the slit light-source. These images are only slightly distorted, whereas the images produced in the liquid zone are broadened about eight-fold relative to the true dimensions of the etched numbers.


(b)

(a)

Fig. 2. Appearance of a tube containing solid, liquid, and an air head-space

(*a*) Stationary; (*b*) spinning at about 1000 rev/min.

The effect is independent of the nature of the light source (a.c. or d.c.) and the speed of the centrifuge, and does not require the repeated presentation of the tube between the light and the observer; indeed, the stationary images are seen if the centrifuge head is rotated manually for only one cycle. A simple stroboscopic explanation, therefore, does not explain the observations.

---

* Marsh, B. B. *Biochim. Biophys. Acta*, 9, p. 247 (1952).

The appearance of the image of a number is influenced by the refractive index of the medium within the tube. This is illustrated by Fig. 3, a photograph of a spinning tube containing, from bottom to top, carbon disulphide (refractive index 1·63), water (1·33), toluene (1·50), and air (1·00). It is seen that the extent to which the image of the number is displaced to the right of the light-source, and also the lateral enlargement of the image, varies with refractive index within the range 1·33–1·63, and that, with a very low refractive index, the image is displaced to the left.

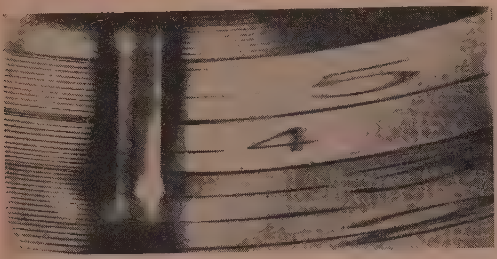


Fig. 3. Appearance of a spinning tube containing materials of different refractive index

Top to bottom: air (1·00), toluene (1·50), water (1·33) and carbon disulphide (1·63).

DISCUSSION

It is convenient to consider as separate cylindrical lenses the empty glass tube and the column of liquid which it contains. The tube alone acts as a very imperfect but weakly diverging lens of focal length approximately + 5 cm, while the column of liquid of radius 0·65 cm has a focal length f given by $1/f = (n - 1)(-2/0{\cdot}65)$, i.e. $f = +0{\cdot}325/(1 - n)$ cm, where n is the refractive index of the liquid. The lens formed by the tube and liquid now considered together has a focal length F given by $1/F = \frac{1}{5} + [(1 - n)/0{\cdot}325]$, i.e. $F = 0{\cdot}305/(1 - 0{\cdot}939n)$ cm. In the centrifuge described above, the light source is 18 cm vertically below the path of the rotating tube, and the distance V of its image from the cylindrical lens (tube + liquid) is given by $1/V = (1/18) + [(1 - 0{\cdot}939n)/0{\cdot}305]$, i.e. $V = 0{\cdot}300/(1 - 0{\cdot}923n)$ cm.

This equation describes the lens in terms of the refractive index of the liquid within the tube. When the refractive index is high (e.g. carbon disulphide, 1·63) V is small and negative, and in consequence the lens is strongly convergent. With a somewhat lower refractive index (e.g. water, 1·33), V is larger and negative; the lens, therefore, is convergent, but rather less so than in the former case. As successively lower values of refractive index are considered, the convergent lens becomes correspondingly weaker until, when $n = 1{\cdot}08$, the weakly divergent nature of the empty tube is compensated exactly by the slightly convergent column of liquid. When the refractive index is near but below 1·08 (e.g. air, 1·00), V is large and positive, the lens being therefore slightly divergent.

This argument is expressed diagrammatically in Fig. 4. Each sketch shows the spinning tube in the two extreme positions in which refracted light reaches the observer's eye E from the light source L, and together the diagrams illustrate the effect of refractive index on the position and size of the image as seen from E. AB represents an etched mark on th upper surface of the tube. When the refractive index of th liquid is high, as in Fig. 4(*a*), the image of A appears whe the tube is in position 1, and of B in position 2, while image of points on the etched line between A and B appear when th tube is in positions between 1 and 2. The image of the lin AB is spread, therefore, over a distance A_1B_2. This reasonin equally applies to Fig. 4(*b*), but because of the somewh lower refractive index of the liquid, the lens is less co vergent and the image of AB extends over a shorter distan A_1B_2. The image is therefore less distorted sideways a less displaced from the line EL than in example (*a*). In t case of a slightly diverging lens [low refractive index, Fig. 4(*c* the first refracted ray of light to reach the observer follo the course LB_1E, and the last ray LA_2E; the image of B th appears to the *left* of that of A, and the resulting image AB is B_1A_2. The image is therefore reversed.

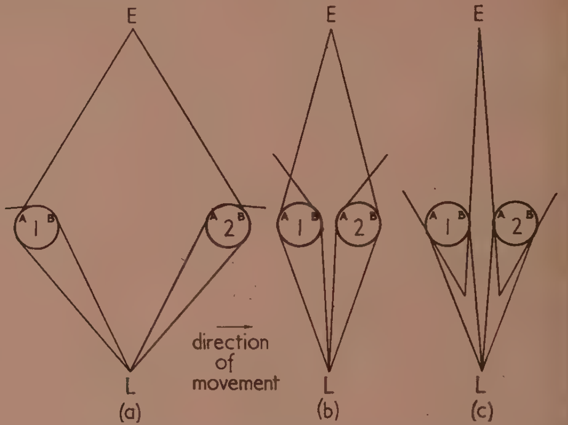


Fig. 4. The effect of refractive index on the nature of the lens, and hence on the image formed

(*a*) High refractive index; (*b*) medium refractive index; (*c*) low refractive index.

Thus the effect is partly stroboscopic in the sense that lig is refracted to the eye by the lens action of the tube o when the tube is in certain definite positions relative to t light and observer. In stroboscopy, however, the *ent* object under observation is illuminated at the same instant each cycle. In this apparatus the tube is "scanned" once each cycle by the image of the light source, this thin line light illuminating successive narrow vertical segments of t tube. The direction of scanning (left to right through t liquid, or right to left through the air head-space) determi the direction which the image faces, while the dista travelled by the tube during a single scanning of its wi determines the extent of lateral distortion and the degree displacement from the light source.

ACKNOWLEDGEMENTS

In its original form, this apparatus was devised duri the author's secondment to the Low Temperature Resea Station, Cambridge. The photographs in the pres communication were taken by Mr. A. L. Tilbury, and first figure was prepared by Mr. R. F. Mulliner. This pa is published by permission of the Director, Domin Laboratory, Wellington, New Zealand.

The final vacua of oil diffusion pumps

By R. F. Coe, M.Sc., Grad.Inst.P., and L. Riddiford, M.Sc., Ph.D., A.Inst.P., Physics Department, University of Birmingham

[*Paper first received* 4 *November*, 1954, *and in final form* 4 *March*, 1955]

Investigations have been made on the properties of several high quality diffusion pump oils. The improvement in final vacua obtainable by fractionating or purifying the oil within the particular pumps used is measured. A limit to this improvement is set by the oil independently of the mechanism by which it is achieved. Measurements of the vapour pressures of the oils by various methods are compared with final pressures measured with both ionization and Knudsen gauges. The residual molecules are vaporous and/or gaseous decomposition products of the oil, and vary with the type of oil. The average molecular weight of the products is substantially less than that of the oil.

1. INTRODUCTION

nce the work of Blears(1) in 1946 concerning the possible rors in ionization gauge readings due to tubulation, the west pressures reported from the use of non-refrigerated l diffusion pumps have been of order 5 × 10^{-7} mm of ercury, measured with a fast ionization gauge calibrated r dry air. In a satisfactory apparatus contributions to the ıal pressure will result only from:

(*a*) the vapour pressure of the pump oil at the temperature of the baffle or the walls of the system being evacuated;

(*b*) thermal decomposition products of the oil in the form of gases and or vapours which escape into the high vacuum from the high speed jet.

can be shown that other effects such as air leakage, outsing and back diffusion, are negligible. It is not possible, owever, to discount directly the existence in the system of aterials, the vapour pressures of which are less than the st pressure obtainable.

The measurements of final vacua reported in this paper ere made part-time during the design and construction of e Birmingham proton synchrotron,(2) which requires a very ood vacuum for successful operation. Many precautions ere taken to insure that the results are reliable, and all easurements were repeated at least once. Studies on the nization gauges employed have already been reported, and will be shown that the Knudsen gauge operates as expected. ne factors which influence the speed of an oil diffusion pump ve been discussed in a previous paper.(3) Many of the easurements reported refer to the 16 in. synchrotron pumps, that discussion refers in the first place to these particular ımps.

2. THE INFLUENCE OF THE PUMP ON THE OIL

The oils at present available commercially have many nilar characteristics, but may differ considerably in the anner in which they perform under operating conditions a diffusion pump. It is possible to obtain quite good cua with commercial plasticizers,(4,5) but our attention s been restricted to refined oils of very low vapour pressure, particular those designated Apiezon B, Apiezon C, ctoil S, and the silicone oil DC 703 in which some of the rbon atoms have been replaced by silicon.

An oil diffusion pump designed to produce a low final essure makes use of the fractionating principle of Hickan,(6) and/or the purifying principle used in glass pumps, d more recently by Latham and others(4) for metal pumps. oth principles depend on the knowledge that oils are ixtures rather than pure compounds, or become mixtures when subjected to pump temperatures (even in the absence of air). If in a multijet pump the jets are fed from separate (but connected) boilers, or from separate towers in the one boiler, the various components of the mixture may be segregated into the various compartments. The components of lowest vapour pressure concentrate in the compartment supplying the high vacuum jet, and the process is called fractionation. If one of the jets is directed into the outlet to the backing pump, and a suitable catchment provided there, the components of highest vapour pressure may be removed from the boiler. This process is called purification.

In Fig. 1 the results of experiments which demonstrate the fractionating principle directly are presented. They were obtained using a three-stage 16 in. pump of a type previously discussed.(3) (The fourth subsidiary jet shown in Fig. 2 was added later for the experiments described below.) The final pressure, recorded with an ionization gauge calibrated for air, is plotted as a function of the clearance *h* between the base of the pump and the bottom of the jet assembly (see Fig. 2). This distance was varied by standing the assembly on three small blocks. Eddies of the type drawn schematically in Fig. 2 will exist in the oil near the base of the pump and these will tend to counteract any segregation resulting from fractionation. For small clearances the pump is completely fractionating as shown by the existence of the first plateau. For larger clearances some re-mixing of the oil occurs, and eventually the pump becomes non-fractionating as is apparent from the existence of the second plateau. The oil level is indicated in Fig. 1. There is a smooth transition through this level showing that re-mixing also takes place in the vapour phase. We have operated a 16 in. pump with various oil charges from 400 to 5000 cm^3 with no detectable change in the final pressure.

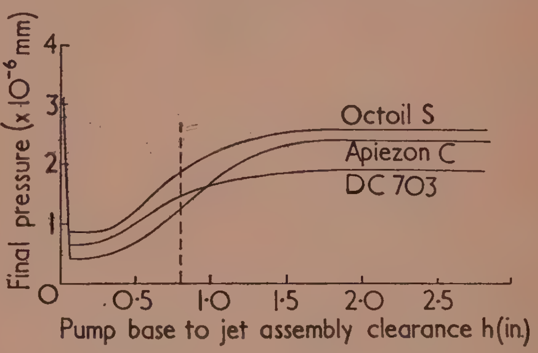


Fig. 1. The effect of fractionation upon final pressure

The speed of the pump is not altered by varying the boiler to jet assembly clearance. The high values for the pressure obtained with an extremely small clearance is, however, associated with a loss of speed. The clearance is too small to permit sufficient oil to reach the high speed jet, which ceases to function correctly. Fig. 1 shows that silicone oil also is (or becomes) a mixture, but that the degree of improvement obtainable by fractionation is not as great as for the pure hydrocarbon oils.

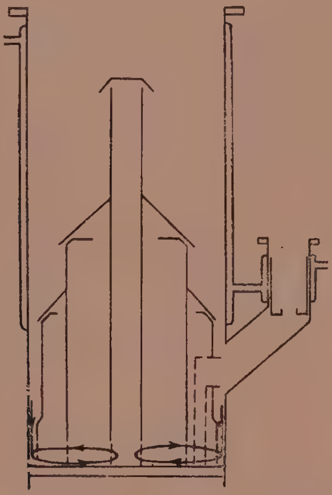


Fig. 2. Diagram of 16 in. oil diffusion pump

By extending the raised jet towers in turn, as indicated by the dotted lines in Fig. 2, it is possible to show that for the high grade oils one good stage of fractionation will give the maximum improvement. The results for Apiezon C oil are presented in Table 1.

Table 1. *Effect of fractionation on final pressure*

Condition of pump	*Final pressure (mm of mercury)*
Completely fractionating	$3 \cdot 8 \times 10^{-7}$
Central tower fractionating	$7 \cdot 0 \times 10^{-7}$
Intermediate tower fractionating	$3 \cdot 6 \times 10^{-7}$
Non-fractionating	$1 \cdot 7 \times 10^{-6}$

That the intermediate tower is a more efficient segregator than the central one is understandable since the throughput of oil is much greater in the low speed jets than in the high speed one. The pump may be considered to have two compartments, and the amount of segregation can reasonably be expected to depend mainly on the rate of flow of oil from one compartment to the other.

A minimal clearance is necessary to ensure an adequate supply of oil to the central tower supplying the high speed jet. For a 16 in. pump the jet assembly is placed on the base plate and a 2 × ¼ in. slot cut in the bottom of each tower. No improvement in final pressure is obtainable by making the oil path connecting the slots tortuous rather than direct. This is understandable for it has already been shown that the re-mixing of segregated portions of the oil can occur readily through the gaseous phase. Thus any segregation in the body of the liquid is immediately offset by contamination of the surface from the vapour mixture above it. The eddies mentioned above flow in the main at right angles to the tortuous path. The result also shows that surging of the oil from one compartment to another is unimportant.

The effect of purification has been investigated for Apiezon C oil in a pump operating in both the fully fractionating and non-fractionating conditions. The purifying "jet" was 2 in. diameter hole cut in the outer tower of the jet assemb opposite the outlet to the backing pump (see Fig. 2). Tl results are presented in Table 2.

Table 2. *Effect of purification on final pressure*

Condition of pump	*Final pressure (fractionating) (mm of mercury)*	*Final pressure (non-fractionatin (mm of mercury)*
Normal	$3 \cdot 8 \times 10^{-7}$	$1 \cdot 7 \times 10^{-6}$
Hole open, no catchment	$1 \cdot 0 \times 10{-}6$	$1 \cdot 8 \times 10^{-6}$
Hole open, with catchment	$3 \cdot 8 \times 10^{-7}$	$7 \cdot 5 \times 10^{-7}$
Hole fed from fourth tower, with catchment	$3 \cdot 8 \times 10^{-7}$	—
Hole fed from fourth tower, no catchment	$5 \cdot 0 \times 10^{-7}$	—

It is evident that it is necessary to trap the more volati components of the oil in a catchment (a volume of a few cr is sufficient) placed in the cold part of the outlet tube as shov in Fig. 2. In the non-fractionating case a substantial improv ment in final pressure due to purification is obtained, b for the fully fractionating case no improvement is obtaine The latter result is consistent with the conclusion previous drawn that one good stage of fractionation is sufficient make the best use of the oil. For the purifying system have used the improvement obtainable in the non-fractionati case is not as great as with one good stage of fractionatic The more volatile components are being continually form in the pump by thermal decomposition. After the pressu of $7 \cdot 5 \times 10^{-7}$ mm was obtained, the purifying jet w blocked and the final pressure then reverted to the form value of $1 \cdot 7 \times 10^{-6}$ mm. This remained unaltered wh the small quantity of oil previously distilled into the catc ment was returned to the pump boiler.

With no catchment the presence of the hole in some w interferes seriously with the performance of the fully fra tionating pump. The effect may be overcome by supplyi the new fourth "jet" from its own small tower (dotted Fig. 2). This suggests that there is normally a form fractionation taking place across the wall of the outer tow Latham and others(4) have lengthened the hot section o 2 in. diameter pump employing a purifying jet so that film of cool oil returning to the boiler from the upper will have more opportunity to volatilize before reaching boiler proper. This process is called falling film fractionatic Lower final pressures were obtained with a pump usi falling film fractionation as well as purification. F Apiezon C oil the pressures obtained with and without falling film were 3·2 and 6×10^{-7} mm respectively (comp Table 2). We have investigated the degree of purificati obtainable with the 2 in. pump, using Apiezon C oil. Af operation at $6 \cdot 0 \times 10^{-7}$ mm the purifying jet was clos and the pressure obtained was $9 \cdot 4 \times 10^{-7}$ mm. The pu was then cleaned and a new oil sample inserted with the still closed. The final pressure was $1 \cdot 7 \times 10^{-6}$ mm wh became $6 \cdot 0 \times 10^{-7}$ mm with purification, and 9·4 10^{-7} mm again when the purifying jet was closed once mc There is evidence for some permanent purification as w as for continuous purification analagous to the continu segregation previously discussed.

The resistance of the various oils to oxidation has a been tested. Without switching off the pump heater, pump was opened to the atmosphere for thirty minu The final pressure obtainable with silicone oil remai unaltered, but for the other two oils it became substanti rse. This supports what is generally accepted about the ustness of the silicone oils.(4,5,7) In our experience, wever, the quantity of burnt matter from Apiezon C oil ich collects on the jet assembly in a pump operating under rmal conditions for prolonged periods, is low. This is value in view of the low final pressure obtainable with the

It is not the case for Octoil S, even when the pump is erating at low pressures, for a black deposit soon forms.

The above results suggest that a major improvement in degree of vacuum obtainable with the present oils, without use of refrigeration, is unlikely. Approximately the same t final pressure for a particular oil is obtained for the and 2 in. pumps by methods which differ in practice. It l be seen below that the limit is probably set by thermal composition of the oil at the temperatures existing in the ilers of efficiently operated pumps.

THE VAPOUR PRESSURES OF DIFFUSION PUMP OILS

The Clausius–Clapeyron equation states that a plot of p against T^{-1} should be a straight line, p being the vapour essure of the oil at the absolute temperature T. Thus if p known at two values of T, its value at any other tem- ature can be inferred. At high temperatures the vapour essure may be measured directly with a hypsometer or by method of direct weighings. Some results for the oils which we have been interested have been taken from les in the book by Dushman,(8) and papers by Burrows(9) d Brown.(7) They are presented in Fig. 3.

For pure compounds, the ratios between the vapour essures at room temperature and at a higher temperature y be obtained by the use of a molecular dew apparatus. is elegant method was developed by Kapff and Jacobs(10) d has also been used by one of us for other oils(11) (not all re compounds). The results quoted in both references, the oils in question, based on the combination of direct weighings measurements at a particular temperature and values for the slopes of ln p against T^{-1} plots estimated from the dew experiments, are also presented in Fig. 3. The dew method records an *upper* limit to the vapour pressure of a pure compound, but for mixtures, the effect of the component yielding the curve of greatest slope only is recorded. We have no curve for Apiezon C oil, but a direct weighings measurements at one temperature showed the vapour pressure to be about five times lower than for Apiezon B oil.

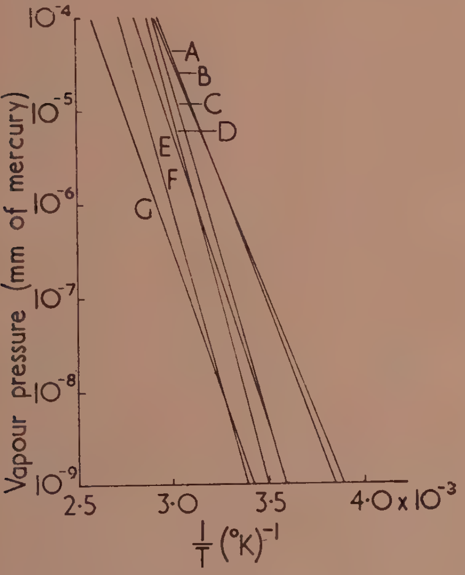


Fig. 3. Vapour pressures of various oils as a function of temperature

A, Apiezon B, Burrows; *B*, Apiezon B, Dushman; *C*, DC 703, Riddiford; *D*, Apiezon B, Riddiford; *E*, Octoil S, Burrows, Dushman; *F*, Octoil S, Riddiford; *G*, DC 703, Brown.

A direct but difficult measurement at low temperatures is possible with a small high vacuum system by recording the pressure before and after the insertion of a small oil sample into the system. Filosofo and others(12) have published a result for Apiezon B oil using a Knudsen gauge, and we have attempted a measurement for Apiezon C oil using both ionization and Knudsen gauges with the apparatus of Fig. 4. Both gauges are mounted directly on to the vessel into which the oil is to be placed. This is connected to a liquid air trap and pump by a tube of speed sufficiently low to ensure that the pressure in the vessel due to the vapour is not very much less than the true vapour pressure. The ionization gauge is placed so that radiation heating of the surface of the oil sample by the hot filament is small. The body of the Knudsen gauge is water cooled and all readings are taken with the oil sample immersed in a bath at a temperature lower than that of the cooling water. The liquid-air trap is kept full to avoid errors due to the oil from the pump (also Apiezon C). A difficulty is that, with such a low pumping speed, the time taken to outgas the system until it is certain that an equilibrium pressure has been obtained may be a week. Several more days may be required to ensure that equilibrium has been attained after the sample has been inserted, despite the fact that it has been outgased previously. Useful checks are that the reading on one gauge must not depend on whether the other is switched on, and that the readings before and after the insertion of the sample should be the same if the cold bath is filled with liquid air. It has been shown that with no sample the gauge readings are not significantly affected by chilling the bath to 0° C.

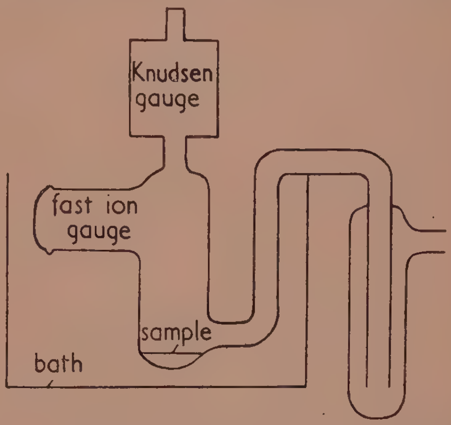


Fig. 4. Apparatus for measuring vapour pressure

Satisfactory results were obtained with the Knudsen gauge. When the ionization gauge was switched on in the presence of the oil sample, however, the readings on both gauges were high. This was presumably due to the cracking of the oil vapour on the hot filament (the effect is not observable in the high speed systems with which other experiments have been performed). The Knudsen gauge had a sensitivity for both air and hydrogen of $6{\cdot}8 \times 10^{-9}$ mm of mercury per mm scale division at 4 m for a temperature difference of 135° C. The pressure due to the sample depends on the temperature of the ionization gauge filament. The gauge used was of the type(13) with which all our work has been performed. The filament was of pure tungsten normally operating at about 2200° C with an electron current of 5 mA.

In Fig. 5 the readings of the ionization gauge, and of the Knudsen gauge with the ionization gauge on, due to the sample, are plotted against the temperature of the bath. With the ionization gauge off, at no temperature was the oil vapour pressure recorded by the Knudsen gauge greater than the lowest measurable with the system, about 1×10^{-8} mm. The Knudsen gauge reading with the ionization gauge off is therefore represented by the abscissa in Fig. 5. This is in agreement with the results previously described for the vapour pressures of high grade oils. The results of Filosofo and others that the vapour pressure of Apiezon B oil at 25° C is 4×10^{-6} mm is inconsistent with these results.

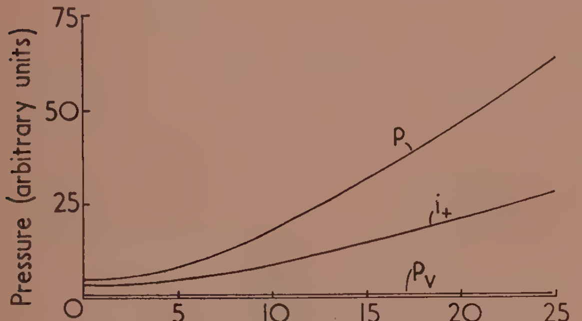


Fig. 5. Pressure due to oil sample as a function of temperature

An analysis of the ionization gauge data is now made, for it yields evidence supporting a simple picture and may be of value if others perform more favourable experiments. It is assumed that the oil is decomposed by the filament into a single "average" product. The rate of destruction of the oil molecules will be proportional to the oil pressure which will never be much less than the vapour pressure. We may then write for the pressure in the system due to the sample,

$$p = p_v + p_d = p_v[1 + (k/S)]$$

with p_v, p_d the contributions from vapour and decomposition product, k the constant of proportionality, and S the speed with which the decomposition products are removed from the system. The ratio p/p_v is a constant and could, in a favourable case where p_v is measurable, be determined from curves such as those in Fig. 5. An interpretation of the ionization gauge readings could then be made. We may write

$$i_+ = S_v p_v + S_d p_d = p_v[S_v + S_d(k/S)]$$

with i_+ the positive ion current, and S_v, S_d the sensitivities of the ionization gauge in μA per mm per mA, for the vapour and decomposition products respectively. The quantities p_v and k/s are known, so that the values of S_d and more importantly the quantity S_v, about which no information is at present available, are obtainable using any two points on the ionization gauge curve.

In the case of Apiezon C, unfortunately, k/S is much greater than unity, so that the above analysis cannot be completed. However, for $k/S \gg 1$ and S_v of the same orde as S_d, then $p/i_+ = 1/S_d$. From Fig. 5 it is evident that p/i is quite closely a constant providing some support for th above theory. S_d has a value 3·8 times the value for ai which is reasonable as will be seen in a later discussion.

4. THE DEPENDENCE OF THE FINAL PRESSURE O THE AMBIENT TEMPERATURE

Use has again been made of the fact that the sensitivity c a Knudsen gauge is independent of the nature of the gas whereas the sensitivity of an ionization gauge is known t depend upon it, this time in the high speed apparatus show in Fig. 6. The pump was a 16 in. fractionating one. Th Knudsen gauge has already been mentioned. It is essentia

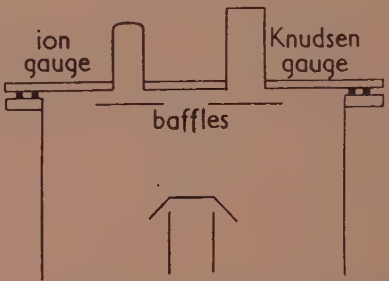


Fig. 6. Apparatus for measuring final pressure

to connect it to the apparatus by a wide-bore connectin tube, and to outgas for about 6–12 h by heating the case t the maximum safe temperature of about 70° C. It is necessar to use rubber ring rather than vacuum wax seals to perfor this operation satisfactorily. The gauge consists of a lig vane freely suspended between hot and cold blocks of copp at temperatures T_1 and T_2° K. It has been shown expe mentally that the sensitivity of the instrument is proportion to $(T_1 - T_2)/T_2$, which assumes that the vane has the te perature of the gas. This is important as a correction fact of about 25% has to be made in the worst case for this reaso

The atmosphere in each gauge consists of any residu gases in the form of decomposition products from the pum together with the saturated vapour pressure of the (deco posed) oil which collects on the cooled baffles. Back streami from the diffusion pump ensures an ample supply of oil o the baffles. These are arranged so that the pumping spee into the working space is low enough to ensure that t vapour is close to saturation pressure there. Pressu measurements were made on each gauge as the temperatu of the water flowing through the baffles and the metal jack of the Knudsen gauge was raised. The glass envelope of t ionization gauge is warmer than the maximum temperatu used. It was considered that should the relative contributi of the oil vapour pressure to the final pressure vary wi temperature, as would be the case were non-condensib gases or vaporous decomposition products with a differe latent heat of evaporation also present, the ratio of ionizati gauge to Knudsen gauge readings would also vary. It wou be possible then to separate out the contributions from t different sources of pressure.

The results for three oils for both gauges are given Fig. 7. At the higher temperatures the curves are straig lines indicating that the residual molecules are, in gener due to vapour components which have much lower heats vaporization than expected from the curves of Fig. 3. Al included in Fig. 7 are the results of experiments similar hose already reported(11) on the effect of refrigerating a erfect one-hit baffle placed between the recording ionization auge and the pump. At the time of the earlier experiments he operation of the pump was not as clearly understood as t present, and the wide variations in final pressure there uggested must now be discounted. As a result of experience vith a large number of pumps and oil samples, it is now onsidered possible to specify in advance the pressure btainable with a particular pump and oil to within 50%, vhich must be considered satisfactory in the region of 10^{-7}–0^{-6} mm air equivalent. It is seen that the slope of all urves decreases as the temperature becomes less than 10° C. n the case of Octoil S this effect was already noticeable at igher temperatures, and at about 10° C the pressure is due ntirely to non-condensible gases. Results published by atham and others(4,5) for the oils of interest here, using a in. purifying diffusion pump employing falling film fraconation and an ionization gauge, are also presented in ig. 7. The results at low temperatures do not differ widely rom the present work, but at higher temperatures the curves ave much steeper slopes.

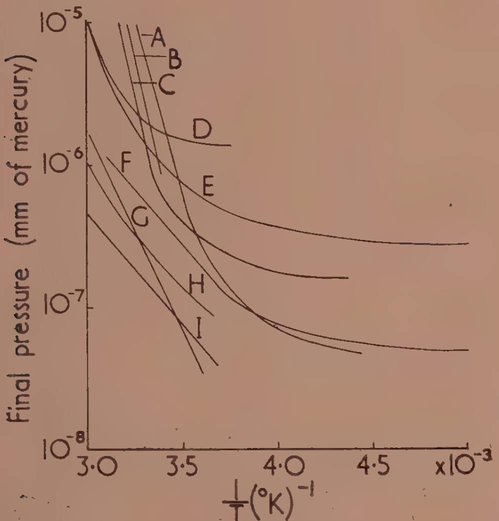


Fig. 7. Final pressures of various oils as a function of temperature

A, DC 703 / *B*, Octoil S / *C*, Apiezon C — Latham;
D, Octoil S / *E*, DC 703 / *F*, Apiezon C — present authors' ionization gauge;
G, DC 703 / *H*, Octoil S / *I*, Apiezon C — present authors' Knudsen gauge.

That the X-ray photoelectric effect does not set a lower mit to the pressures measured with the ionization gauge is vident, since pressures of the order of 1×10^{-8} mm have een obtained by refrigerating with liquid air. This also hows that air leakage is negligible, as was found from a nowledge of the leak rate of the system and the speeds of he pump and tubulation to the gauges. As indicated preiously, a lower limit to the final pressure could be set by ontaminants of low vapour pressure. Presuming that the ffect of these was a constant throughout the experiments, nd that in case *F* (Fig. 7) all the pressure at low temperatures rises from this cause, the marked change in slope in cases and *E* is nevertheless scarcely affected.

The ratio of the pressure measured with the air-calibrated ionization gauge to that measured with the Knudsen gauge varies from 3 to 11 for the different oils. The ratios are plotted as a function of the temperature of the baffles and Knudsen gauge jacket, and of the Knudsen gauge pressure, in Fig. 8. Only in the case of silicone DC 703 oil is there real evidence for a change in the nature of the residual molecules with temperature. The slight effect for Apiezon C oil is scarcely outside the experimental error. It is surprising that in the case of Octoil S no effect was found. The conclusion is that it is not possible by this method to distinguish between vaporous and gaseous decomposition products. For silicone oil the change could be due to the presence of more than one kind of vapour.

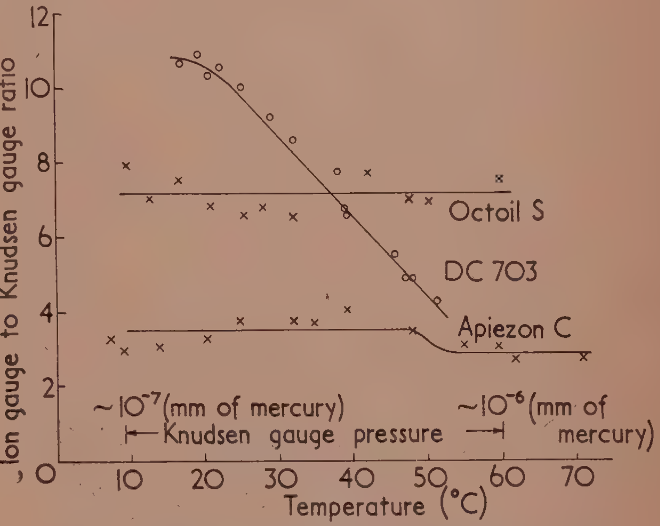


Fig. 8. Ratio of ionization gauge to Knudsen gauge readings as a function of temperature

5. DISCUSSION ON THE NATURE OF THE RESIDUAL MOLECULES

The measurements discussed in Section 3 show that the vapour pressures of the three main oils under discussion in this paper are less than 10^{-8} mm at or about room temperature. The measurements summarized in Fig. 7 show that the final pressures measured with a Knudsen gauge are of order 10^{-7} mm at or about room temperature. Consequently, it is certain that at room temperatures and lower the final pressure is not due to the pure oil. At the highest temperatures of about 60° C used in the experiments described in Section 4, the final pressures are of the same order as the oil vapour pressures. This means that the oil vapour should commence to play the most important role at about this temperature. The results of Latham and others yield curves of a much steeper slope and if they are correct, on the basis of the present argument the contribution of the oil vapour pressure should be small even at the highest temperatures.

It is presumed that the vapour predominant at room temperature is produced by thermal decomposition of the oil in the pump boiler. The difference in slope between the curves of Figs. 3 and 7 is also evidence for this. Further the results in Fig. 7 refer to fractionated oil and would be higher were the pump operating in a non-fractionating state. Presumably the decomposition proceeds continually at a relatively slow rate in the boiler. An explanation of the strong effect of the products on the final pressure must be sought. Hickman(14) has shown that the effect of contaminants can be more important than would be anticipated. With a mixture of Octoil and Octoil S the percentage of Octoil which migrates to the high vacuum side of a fractionating pump is much greater than would normally be expected. A state of equilibrium would have to be reached between the rate of decomposition and the rate of removal of the product from the system (through the backing pump).

Most of the curves in Fig. 7 show a change in slope at the lower temperatures. This is particularly marked for Octoil S and shows clearly the presence of a non-condensible gaseous decomposition product. In this case there is no doubt that the process is a continuous one. Whether the gas is the end-product of the initial decomposition or produced directly from the pure oil is uncertain. The evidence that small and large pumps yield similar final pressures, however, favours a gaseous end product in all cases, which would make similar states of equilibrium possible. It has been shown that purification must be carried out continuously, suggesting that it takes place after decomposition. It is known, however, that a low vapour pressure oil in general results in a better vacuum. It could be then that an initial segregation or purification occurs before decomposition takes place. Alternatively pure oils are more stable.

The results in Fig. 8 mean that the gaseous decomposition products are similar in character to the vaporous decomposition products, or that the sensitivity of an ionization gauge is the same for both. As has already been shown, the highest temperature used is probably not high enough for any effect due to the oil to be apparent. Obviously the decomposition products will have an average molecular weight lower than that of the oil (about 500) and higher than the weight of an average constituent atom (say 14). Found and Dushman(15) have found that for molecules up to the mass of iodine, the sensitivity of an ionization gauge is proportional to the molecular weight. If this law is true for the decomposition products, then from Fig. 8 it follows that the products of Apiezon C, Octoil S and silicone DC 703 oils present at room temperature have average molecular weights of about 93,207 and 312 respectively. Since the residual molecules may be substantially lighter than the primary oil molecules, figures for final pressures obtained by normalizing an ionization gauge reading from air to oil in the ratio of the molecular weights, as was done in some early papers, should be treated with caution.

Further evidence on the nature of the average residual molecules is obtained from experiments on the scattering of the proton beam in the Birmingham synchrotron by the residual gas molecules. The amount of scattering and hence the reduction in the number of particles successfully accelerated, depends on the gas pressure and the nature of the residual molecules. The experiments of interest in the present case involve the use of high speed liquid air traps placed between the pumps and the vacuum vessel of the synchrotron. In the Birmingham synchrotron it can be shown that about one-third of the final air-calibrated ionization gauge reading should be due to decomposition products from the pumps, which use Apiezon C oil and are noter frigerated, except that the water-cooled baffle at the top of each pump is a few degrees below room temperature. The liquid air traps eliminate this component. The synchrotron beam intensity was measured before and after the application of liquid air, and also when sufficient air was allowed to enter the system through artificial leaks to make the ionization gauge galvanometer deflexion equal to what it was before the liquid air was applied. The results are summarized in Table 3.

Table 3. *Effect of refrigeration on synchrotron beam intensity*

Condition of apparatus	*Ionization gauge pressure (air equivalent)*	*Synchrotron beam intensity (normalized)*
Normal	$2\cdot0 \times 10^{-6}$ mm	3·0
Liquid air traps full	$1\cdot3 \times 10^{-6}$ mm	4·9
Air leaks open	$2\cdot1 \times 10^{-6}$ mm	1·7
Leaks closed again	$1\cdot2 \times 10^{-6}$ mm	4·7

Air results in 1·7 times the loss of beam caused by th equivalent ionization gauge reading due to the residual molecules from the pump. The sensitivity of the ionization gaug for Apiezon C decomposition products is 3·2 times the ai sensitivity, so that the air pressure was 3·2 times the pressur of the decomposition products. It may be reasonabl assumed that the average atom in a decomposition produc molecule is equivalent in scattering power to a constituen atom of an air molecule, and that the beam intensity decrease exponentially with the number of atoms per cm^3 present i the vacuum tube. It is then possible to show that the averag molecular weight of the decomposition products fro Apiezon C oil is about 51. This is substantially lower tha the value of 93 inferred from the Found–Dushman law, bu at least it can be said that the decomposition products fro Apiezon C are quite light. The difference could be due partl to the liquid air traps removing some vapour from th vacuum vessel of the synchrotron as well as preventing th flow of molecules backwards from the pump.

Other workers have investigated the nature of the residua molecules using a mass spectrometer. Blears(16) found tha the mass spectrum of the residual gases is complex, and tha without a cold trap the spectrum of hydrocarbon molecul from the pump continues up to mass numbers of sever hundred. Hisatake and Matsuda(17) have published complete hydrocarbon spectrum for a pure sample of alky naphthalene, introduced into the spectrometer which separated from the apparatus by a liquid air trap, up mass number 380. These results are extremely useful demonstrating the complexity of the residual molecules, b it is difficult to obtain absolute data because of such facto as oil decomposition in the ion source.

ACKNOWLEDGEMENT

The working parts of the Knudsen gauge used in t above experiments belong to a gauge kindly made availab to us by Dr. C. A. Ramm.

REFERENCES

(1) Blears, J. *Proc. Roy. Soc. A*, **188**, p. 62 (1946); *Natu* [*London*], **154**, p. 20 (1944).
(2) *Nature* [*London*], **172**, p. 704 (1953).
(3) Riddiford, L., and Coe, R. F. *J. Sci. Instrum.*, **31**, p. (1954).
(4) Latham, D., Power, B. D., and Dennis, N. T. *Vacuum*, **1**, p. 97 (1951).
(5) Latham, D., Power, B. D., and Dennis, N. T. *Vacuum*, **2**, p. 33 (1952).
(6) Hickman, K. *J. Franklin Inst.*, **221**, p. 232 (1936).
(7) Brown, G. P. *Rev. Sci. Instrum.*, **16**, p. 316 (1954).
(8) Dushman, S. *Scientific Foundations of Vacuum Tec nique*, p. 222 (New York: J. Wiley and Sons In 1949).

9) Burrows, G. *J. Soc. Chem. Ind.*, **65**, p. 360 (1946).
0) Kapff, S. F., and Jacobs, R. B. *Rev. Sci. Instrum.*, **18**, p. 581 (1948).
1) Riddiford, L. *J. Sci. Instrum., Supp. No.* 1, **28**, p. 47 (1951).
2) Filosofo, I., Merlin, M., and Rostagni, A. *Nuovo Cimento*, **7**, p. 69 (1950).
(13) Riddiford, L. *J. Sci. Instrum.*, **28**, p. 375 (1951).
(14) Hickman, K. *Rev. Sci. Instrum.*, **22**, p. 141 (1951).
(15) Found, C. G., and Dushman, S. *Phys. Rev.*, **23**, p. 734 (1924).
(16) Blears, J. *J. Sci. Instrum., Supp. No.* 1, **28**, p. 36 (1951).
(17) Hisatake, K., and Matsuda, K. *J. Phys. Soc. Japan*, **8**, p. 416 (1953).

An improved construction of the Smith bridge, type 3

By C. R. Barber, B.Sc., F.Inst.P., A. Gridley, B.E.M., and J. A. Hall, B.Sc., A.R.C.S., D.I.C., F.Inst.P.,
National Physical Laboratory, Teddington, Middlesex

[*Paper received* 25 *February*, 1955]

A new construction of a bridge for resistance thermometry according to the design of F. E. Smith(1) is described, and details of the layout, methods of construction and temperature control are given. The bridge incorporates a new type of resistance coil of high stability and has been shown to be capable of measuring resistances with a reproducibility of a few parts in 10^7 without the need for frequent re-calibration.

1912 F. E. Smith(1) described four designs of bridge for se in resistance thermometry, and the first to be made ommercially according to his third method has been in se at the National Physical Laboratory since 1923. Thirty ears' experience has confirmed the excellence of the design, ut the stability of the coils in this bridge leaves a good deal be desired. For work of the highest accuracy it has been ound necessary to calibrate the bridge at intervals of about x weeks, and, even so, the random changes of resistance f the coils between calibrations (of the order of 1 or 2 in 0^5) have made it impossible to study the constancy of hermometers and the reproducibility of fixed points to the ccuracy which is required nowadays in the maintenance of ne International Temperature Scale.(2)

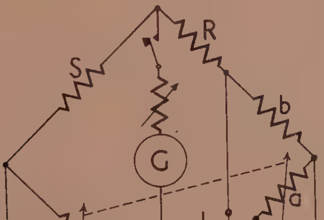


Fig. 1. Circuit diagram of Smith bridge, type 3. $S = b = 100\,\Omega$; $R = 10\,\Omega$, P = resistance thermometer bulb; L_1, L_2, L_3, L_4 = thermometer leads; $a = (Q + 10)/0{\cdot}99$

For thermometry, it is not necessary to know resistances absolutely but only ratios of resistances, though, for certain purposes, such as international intercomparisons of thermometers, it is desirable that absolute values should also be known. But to determine ratios accurately with a decade bridge it is essential that the relationship between the values of successive decades should remain constant, and even this

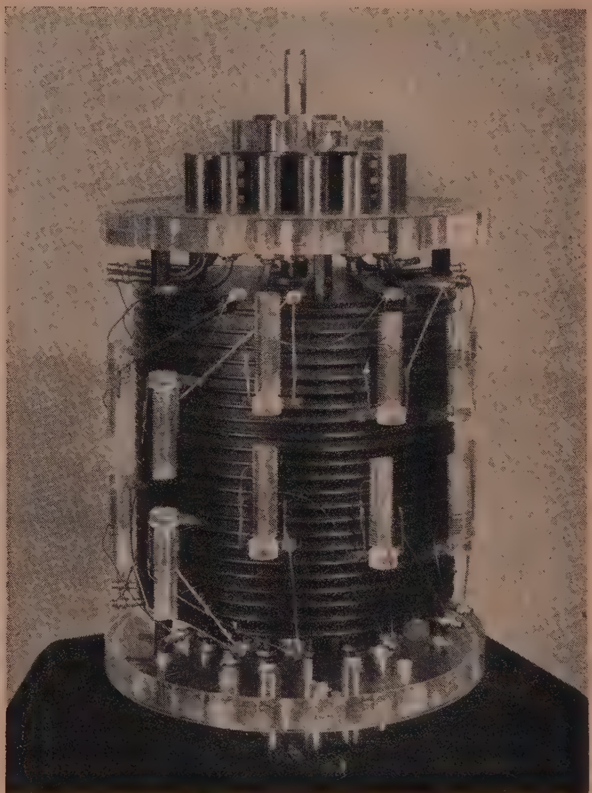


Fig. 2. Assembly of ×1000 bank of Q and a coils, showing switches and adjusting bobbins

requirement was not sufficiently well met with the old bridge. It was therefore decided that a new bridge was necessary.

GENERAL FEATURES OF THE BRIDGE

After consideration of the other designs which have been suggested, the type 3 Smith bridge was again adopted, largely on account of its speed in operation, it being the only bridge with which measurements can be made to an accuracy of 0·0001° C with a single setting of the dials. It is of little value to use equipment capable of measuring fixed points to a high degree of accuracy if other temperatures (which are not, in general, quite steady) cannot be measured with comparable precision: speed then becomes important and the ability to read with a single setting is invaluable. The second advantage of the type 3 Smith bridge is that, since it employs a ratio of 100 : 1, variations of contact resistance in the measuring arm are effectively reduced to one hundredth, so that the use of mercury cups or screw-down contacts is unnecessary. On the other hand, this feature of the design necessitates the use of 1000 Ω coils in the measuring arm of the bridge, and such coils are notoriously less stable than those of 10 Ω. A further disadvantage is that the construction of the bridge is somewhat complicated since the Q and arms of the bridge (Fig. 1) are varied simultaneously, whil according to the original design, the a coils have to be mad to odd values, since the basic equation of the bridge

$$P = \frac{QR}{S} + (L_3 - L_2)\frac{R}{S} + \frac{L^2}{a+b}\left(\frac{2R}{S} + \frac{b}{S} - 1\right) \qquad (1$$

only holds if

$$a/b = (Q + R)/(S - R) \qquad (2$$

and this reduces to $a = 10/0{\cdot}99 + Q/0{\cdot}99$ when $S = b =$ 1000 Ω and $R = 10$ Ω. Since the bridge was built, Gautier has shown that by making $b = S - R$, this relationshi becomes $a = 10 + Q$, thus eliminating the need for odd value coils. The third term in the balance equation is generall insignificant, L being very small compared with b, an provided that reasonable care is taken in matching L_2 and L the term $(L_3 - L_2)R/S$ is also small and has a negligible effec on resistance ratios. For absolute determinations o resistance it may be eliminated by reversing the lead (4, 3, 2, 1 for 1, 2, 3, 4).

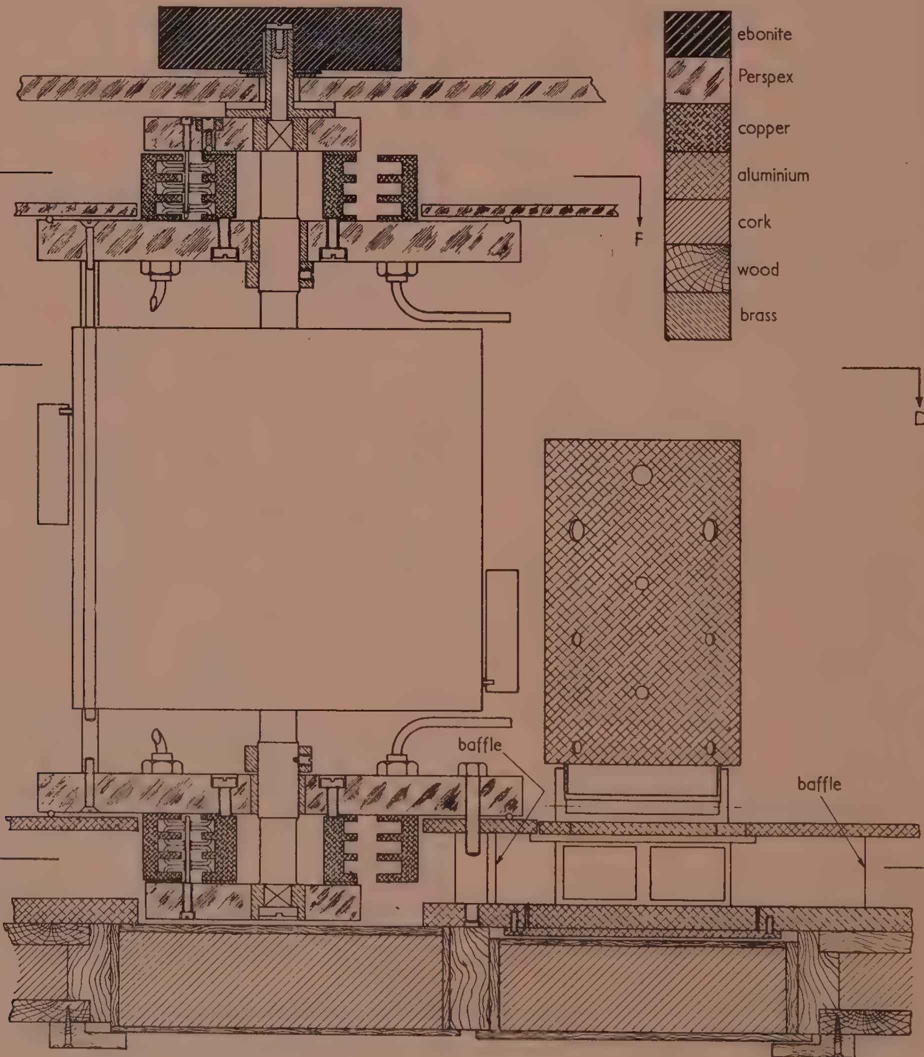


Fig. 3. Vertical section through part of bridge space, showing ×1000 bank of coils and an air distributor

Experiments were first made to evolve a design for 1000 Ω oils of high stability, and the successful result of these has lready been reported.(4) Further, since it was required to nake measurements to 0·0001° C without galvanometer nterpolation, a 7-decade bridge became necessary, the mallest steps being of 0·001 Ω, with the consequent necessity of having a zero stability of the order of 0·0001 Ω in the *Q* rm. As a result of discussions with H. Tinsley and Co., Ltd., vho supplied the switches and carried out the wiring and djustment of the bridge, it was decided to make the last wo decades as shunted dials. This means that the *Q* arm of the bridge cannot be reduced below about 0·48 Ω, and, or convenience in reading, this has been made up to 1 Ω, nd the ×1 decade has been figured 1 to 11 instead of 0 to 10. Standard coils, for use in calibration, have been provided in he bridge, and these have values lying between 10·01 and 0·02 Ω and 100·01 and 100·02 Ω. These values have been hosen so that the coils may be measured by several combinations of decades on the bridge, thus giving a check on he consistency of the calibrations of the decades. (See a ater Section on the performance of the bridge.)

In order to secure the necessary constancy of zero, large witches of Tinsley design(5) are used. The studs are of ellurium-copper, 3/4 in. (19 mm) in diameter, and the aminated brushes are of cadmium-copper. Thermal e.m.f's etween these two alloys were found to be insignificant; less han 1 μV per °C. The brushes are double, working in slots n the studs, so that each brush makes two contacts in parallel. Brushes may, in turn, be paralleled by increasing the number of slots in the studs, and experiments were made with switches naving one, two and three brushes in parallel. The results uggested that two would probably be adequate, but that hree would be quite safe. In consequence, the three-brush lesign (see Figs. 2 and 3) was adopted.* Similar switches vere also used for the *a* arm of the bridge, though here it vould have been satisfactory to use the single-brush type ince the *a* arm does not enter directly into the measurement nd a stability of zero of 0·001 Ω would be adequate (see a ater Section on the adjustment of the bridge).

THE RESISTANCE COILS

The construction of the 1000 Ω coils of the bridge has lready been described(4) and Fig. 4 shows the appearance of finished coil, complete with its adjusting bobbin. The main oil is of 38 s.w.g. bare Minalpha (manganin) wire, mounted n a Perspex (polymethyl methacrylate) disk so as to be as ree from constraint as possible. An external adjusting obbin of 22 s.w.g. bare wire is provided and 1 mm length of this corresponds to about 1×10^{-6} of the resistance of the nain coil. Adjustment can thus be made with the aid of a nillimetre scale, and scraping of the wire is normally unecessary. Twenty coils (ten *Q* and ten *a*) are needed for ach decade, and these are assembled in a series of shallow ast aluminium trays. Pure aluminium is used so as to get he highest possible thermal conductivity and the castings re, in consequence, not as sound as if an alloy had been sed. However, the presence of a few blowholes is mmaterial. The trays are shaped as shown in Fig. 5, and re deep enough to enable the Perspex disks to be supported ntirely by their tongues (see reference (4), p. 69). This esult was achieved by measurement with feelers and the use f strips of Cellophane tape on either side of the tongue until the assembly was just gripped between successive trays. The trays are bolted tightly together so as to form a finned block which can be handled as a unit, independently of its supports in the chassis of the bridge. The complete assembly of 1000 Ω coils and the corresponding *a* coils is shown in Fig. 2. The *Q* switch is above, and the *a* switch below the assembly.

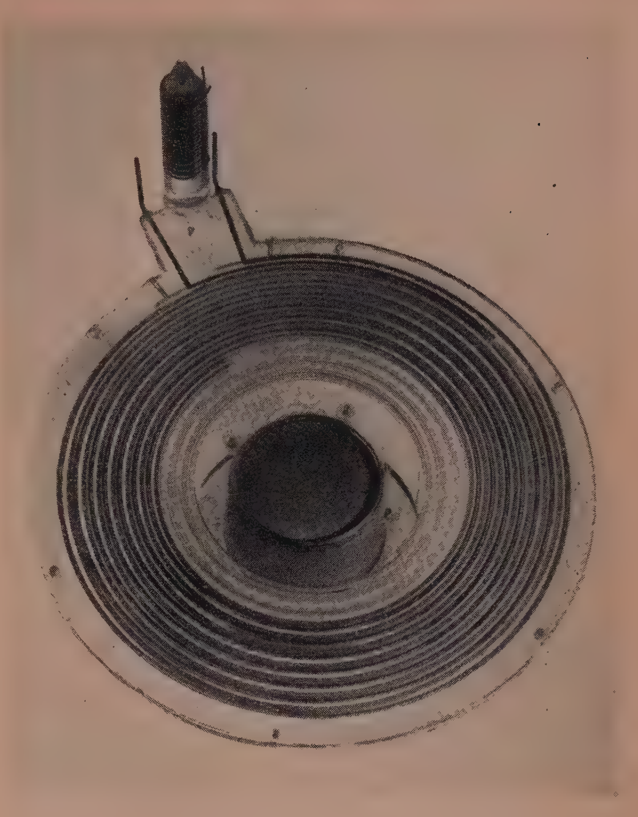


Fig. 4. 1000 Ω coil and adjusting bobbin

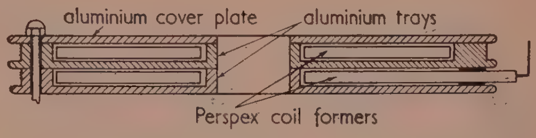


Fig. 5. Two coil formers in aluminium trays with cover-plate

The 100 Ω coils of the next decade are made of the same gauge of wire as the 1000 Ω coils, and two coils are mounted in each disk [Fig. 6(*a*)]. For the 10 Ω coils, 28 s.w.g. wire is used in somewhat thicker Perspex disks, and it was found possible to accommodate five coils in each disk [Fig. 6(*b*)]. The 1 Ω coils were made from 22 s.w.g. bare wire wound in a bifilar helix 15 mm in diameter and about 65 mm long, supported on mica crosses mounted between Perspex end-plates, by means of which they were located in holes drilled through an aluminium block. It would no doubt have been satisfactory to make these coils in the conventional way, since a stability of the order of 1 in 10^4 is sufficient in the fourth decade. The remaining decades (0·1 Ω coils and the two shunted dials) were made by H. Tinsley and Co. Ltd., with the usual silk and shellac insulation.

The ratio assembly consists of three coils in series: 10 Ω, 990 Ω and 10 Ω, the *S* arm being divided into 10 and 990Ω sections for the purpose of a ready check on the adjustment of the *a* arm of the bridge.⁽¹⁾ These coils have all been wound with the 28 s.w.g. bare wire used for the 10 Ω coils in the *Q* and *a* arms, and occupy nine of the thicker disks. The ratio coils normally carry a greater current than the measuring coils (up to ten times as much) and should therefore be made large enough to dissipate the extra energy.

---

* For the sake of clarity the brush laminations are not fully hown in Fig. 3.

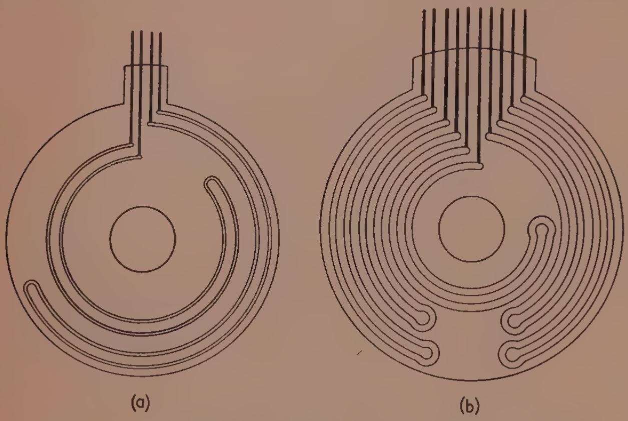

(a) (b)

Fig. 6. (*a*) 100 Ω coil former, (*b*) 10 Ω coil former

The use of the same wire throughout the assembly ensures that the heating effect is very nearly the same in both arms of the ratio (though the energy is probably dissipated somewhat more efficiently from the 10 Ω coils, placed at the ends of the assembly) while the temperature coefficients will be exactly the same. Also, it is probable that the drift of resistance with time of the two arms of the ratio will be proportionate.

LAYOUT AND TEMPERATURE CONTROL

The use of aluminium blocks to equalize the temperature over the coils makes oil-immersion unnecessary, and air circulation based on the design of Sears and Barrell⁽⁶⁾ has been used. By this means, the working space of the bridge is continuously swept by well-mixed air, and is, at the same time, jacketed on all sides by air at the same temperature. In order to avoid difficulties in temperature control during hot weather, and to secure a low temperature coefficient of the coils, the bridge is maintained at 27° C. Since no liquid is used in the bridge there is no need for it to be operated in the horizontal position. It has, therefore, been mounted at an angle of 45° for greater convenience in reading, and built into a structure similar to a pedestal desk (Fig. 7).

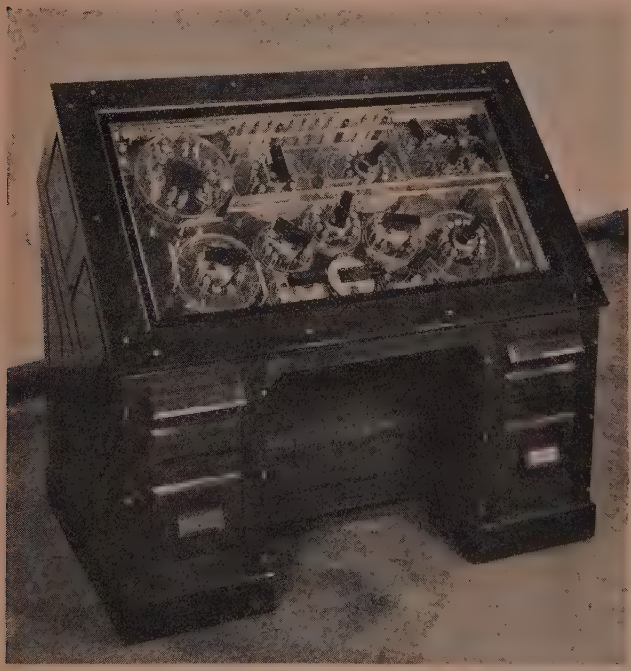
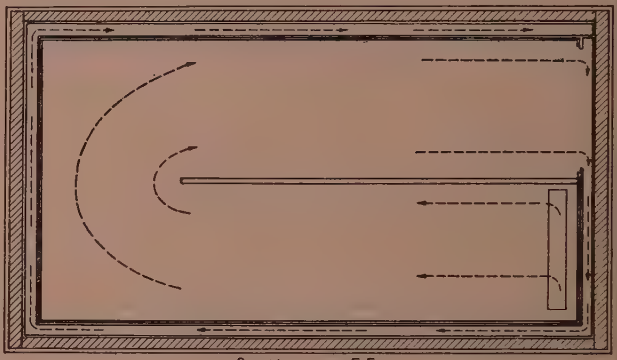
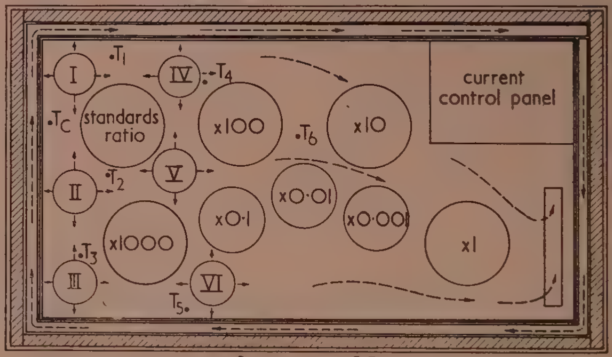


Fig. 7. General view of bridge

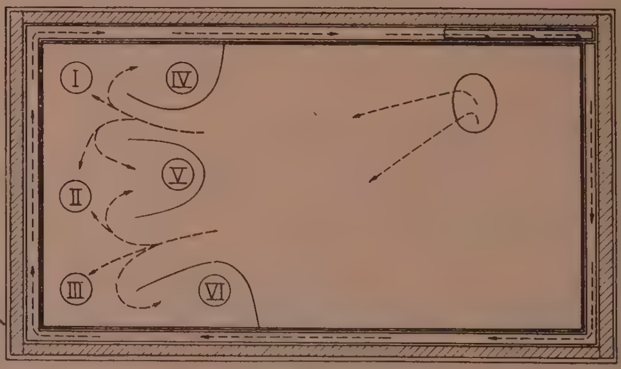
Fig. 8 shows three sections through the bridge, parallel to the base at the planes indicated in Fig. 3. The seven decades are arranged on arcs of two concentric circles, so as to group the last three as close together as possible in front of the observer. All the banks of coils are placed at the same average height, except the ratio bank which is somewhat lower, so as to leave room for the standard coils above it.



Section on EF



Section on CD



Section on AB

Fig. 8. Horizontal sections through bridge space, showing location of air distributors (I to VI), thermometers (T_1 to T_6), contact thermometer (T_c) and coil banks

hese are carried by a removable section of the bridge anel and can thus be taken out for comparison with other andards. The back right-hand corner is occupied by the urrent control panel. This comprises four resistance decades: 10 000, ×1000, ×100 and ×10. A 6 in. (152 mm) milliameter with 125 graduations is placed directly in front of the bserver and has ranges of 2·5, 12·5 and 25 mA. The lector switch for these ranges introduces fixed series resisnces of 17 500, 1900 and 150 Ω respectively so as to give me protection against overload. A 50 V battery is used, nd thermometer currents ranging from 0·25 to 2 mA for ridge readings from 8 to 111 Ω may be obtained.

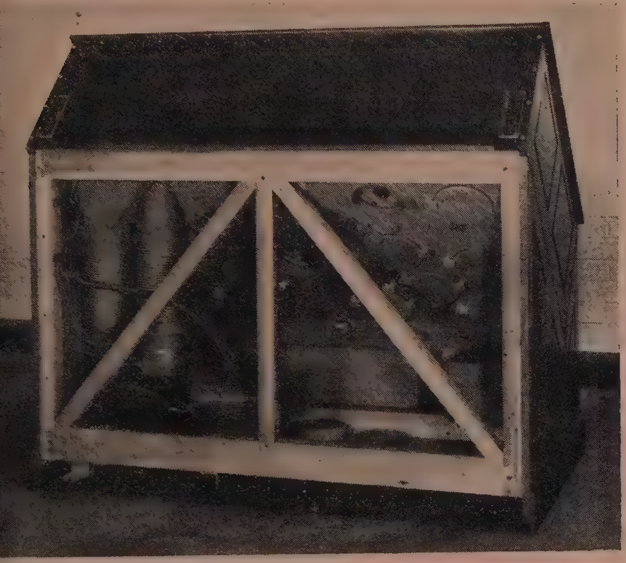


Fig. 9. Back of bridge, showing air circulator and access to dampers of air distributors and switches in *a* arm

Air is supplied by a 4 in. (10 cm) air circulator (Pattern 2780 y Keith, Blackman and Co.) driven at 1440 rev/min by a quirrel-cage motor. The motor is housed inside one of the edestals of the bridge (Fig. 9), and is water-cooled so that e bridge temperature can be maintained during the hottest ummer weather. The air enters the space under the bridge ection *AB*) through the elliptical hole, streams across to he left and passes vertically into the bridge space through he six apertures, I to VI, the flow through each being egulated by means of an adjustable damper. Baffles are rovided so that the air path is of approximately the same ngth to each of the apertures, and the six streams of air ntering the bridge space (section *CD*) will thus have been ubjected to equal cooling, and will arrive at the same temerature. In the original design, these streams of air were elivered through spinning cowls, as used by Sears and arrell, but these were afterwards replaced by fixed distriutors of the same size and drilled with holes as shown in ig. 5. These proved to be at least as satisfactory as the pinning cowls, and their use eliminated a maintenance roblem. The distributors are placed at a lower level than e banks of coils to allow for the vertical component of the r velocity.

There is violent circulation of air round the most important ils (ratio, standards, ×1000 and ×100) and the air then asses across the bridge space and leaves by the slot in the wer panel at the right, and enters the space between the vo panels (section *EF*). A partition between the panels nsures that the air makes a complete circuit before leaving by the slot in the right-hand wall to enter the space which surrounds the bridge. It makes a circuit of this in a clockwise direction and finally leaves by the slot at the back right-hand corner (section *AB*) on its way back to the blower by way of a fan-shaped tube. Except in the bridge space itself, the cross-sectional area of the air passage remains sensibly constant at about 12 in.^{2} (80 cm^2).

Temperature control is effected by means of a mercury contact thermometer (T_c) (supplied by Short and Mason Ltd.) fitted at the left of the bridge space (Fig. 8). This thermometer operates a valve relay which takes about 3 μA a.c. and makes or breaks the heater circuit with a tilting mercury tube switch. In order to avoid the risk of overheating the bridge in the event of a failure of the thermostat with the contacts closed, a simple bi-metallic thermostat mounted in the bridge space is placed in series with the heaters. This thermostat has a wide differential (25 to 30° C approximately) so that in the event of such a failure the temperature will still be controlled within these limits. The temperature is measured by means of six mercury thermometers T_1 to T_6. When the ambient temperature is 20° C, about 100 W are necessary to maintain the bridge at 27° C. About 25 W are supplied by resistance mats at the exit of the fan, another 25 W by a grid of fine nickel-chrome wire where the air enters the space between the two panels, and about 50 W in the annular space round the bridge. This latter is supplied from an asbestos-woven wire resistance mat 12 ft (3·7 m) long completely encircling the bridge. The three heaters are independently controlled, and are adjusted so that the temperature between the panels and in the wall-space is approximately the same as that in the bridge-space itself. When this balance is achieved, a Variac transformer is used to adjust the voltage applied to the whole system until the on and off cycle of the thermostat is reasonably symmetrical. In order to avoid electrical interference with the measuring circuit, the aluminium box which houses the coils of the bridge is earthed.

The bridge panels are made of Perspex, and the engraving is on the under side of the upper panel. This panel is illuminated from the edge by ten 6·5 V, 0·3 A lamps operated on 4·6 V. The use of these lamps affects somewhat the temperature distribution in the bridge, which can be modified by adjustment of the dampers on the air-distributors,

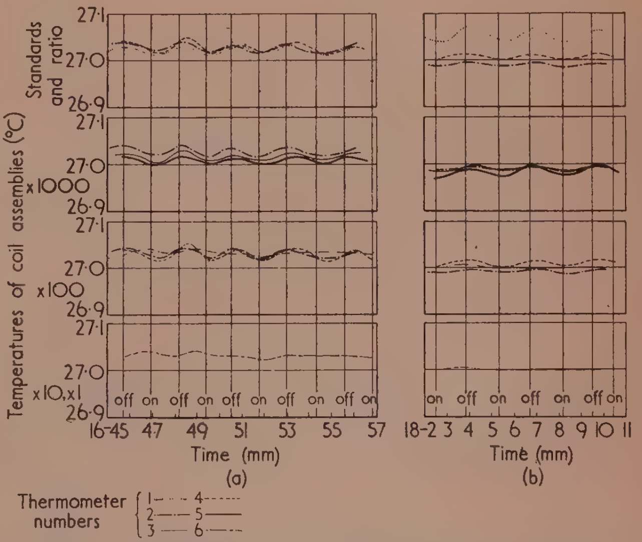


Fig. 10. Performance of bridge thermostat (*a*) without panel lighting, (*b*) with panel lighting

which are reached by way of removable sections of the cork lagging under the bridge. This adjustment has been made with the lamps on, and the result is shown in Fig. 10(*b*). The most important region of the bridge is that containing the 1000 Ω coils (indicated by thermometers 2, 3 and 5) and this is evidently very uniform. Thermometer 1 is the only one which is rather discrepant, but this only affects the ratio assembly (of which the temperature is not of the first importance) and the standard coils. Switching off the lamps [Fig. 10(*a*)] brings thermometer 1 more closely into line at the expense of a slight worsening of the distribution round the 1000 Ω coils. For this reason, the lamps are not switched on when the standard coils are being used in the calibration of the bridge. It has been found that the temperature control at any point remains constant to within ±0·01° C over prolonged periods, while Fig. 10 shows that "hunting" of the air temperature is of the order of ±0·01° C. It was found experimentally that the lag constant for a typical bank of coils was about 50 min. Consequently, fluctuations of temperature inside the blocks are entirely negligible with the normal period of temperature oscillation of about 2½ min. The whole of the air in the working space of the bridge is uniform in temperature to about 0·04° C.

When the bridge is not to be used for a day or two (as at week-ends) the air circulation may be stopped. When this is done, the fan uptake and panel heaters are switched off and the voltage is suitably increased. Under these conditions, the variations in air temperature over the working space of the bridge amount to about 0·5° C, and the period of temperature oscillation becomes about 30 min with an amplitude of about ±0·03° C.

ADJUSTMENT OF THE BRIDGE

When a bridge is intended for work of the highest accuracy, so that it will never be used without the application of corrections, it is not normally necessary that the coils should be adjusted to be exceptionally close to their nominal values. With the type 3 Smith bridge, however, it is essential that the relationship $a/b = (Q + R)/(S - R)$ should be satisfied very accurately. Gautier has shown(3) that, with the arrangement used in our bridge, the error introduced by the third term in equation (1) is $2L^2R/S(a + b)$, so that a limit is set to the permissible value of L. If we accept 0·00001 Ω (0·0001° C, or one stud of the last decade) as the maximum value for this error, we arrive at the positive smooth curve in Fig. 11 as the maximum value of L for different resistances of the thermometer. M. Gautier has drawn our attention to the fact that, by combining this information with the expression $da = (a + b)dP/L_2$ connecting the error produced in P by an error in adjustment of a, we can arrive at the greatest precision that is worth while in making this adjustment. If we assume, again, that we can tolerate an error of 0·00001 Ω in P, we find that da becomes one fiftieth of the maximum lead resistance. The smooth curves of Fig. 11, therefore, give the limits to which a may profitably be adjusted.* The irregular curve shows the state of adjustment as it was in March 1954. For values of P between 20 and 30, 50 and 60, and 70 and 100 Ω, the maximum lead resistance must be slightly reduced if the standard of accuracy in absolute measurement of resistance which we have postulated is to be attained. The downward tendency of the curve is due to the fact that the resistance of the b coil was at that time a fe parts in a million too high.

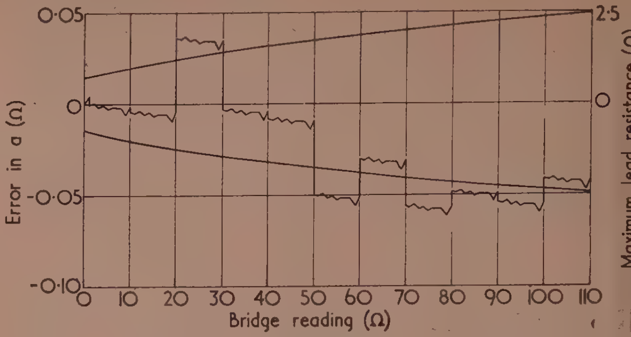


Fig. 11. Maximum permissible lead resistance and accuracy of adjustment of *a* arm

MODE OF OPERATION

As it is important in resistance thermometry to use small measuring current in order to minimize self-heating o the thermometer, the galvanometer should be of high sensitivity. We have used a development of the photoelectri galvanometer amplifier system described by Preston(7) whic gives a maximum usable sensitivity of about 2·5 mm fo 10^{-10} A. Since deflexions of about 0·25 mm may b observed, the limit of detection is about 10^{-11} A.

In order to eliminate stray thermal e.m.f.'s in the circuit balance is always made by reversing the battery current an observing that the galvanometer spot does not move, o shows no acceleration or retardation of any drift which ma be present. This method of working has the additiona advantage of doubling the sensitivity. Our standard practic is to work with a current of 0·5 mA in the thermomete but, in the most accurate work, measurements are also mad at 1 mA and 0·25 mA and the values obtained are extrapolated to find the resistance with zero current. With current of 0·5 mA a balance can be obtained to an accurac of about 0·00002° C in a few seconds with a thermomete having a fundamental interval of 10 Ω.

PERFORMANCE OF THE BRIDGE

Now that the bridge has been in service for nearly thre years the quality of its performance over an extended perio can be assessed. Fig. 12 shows the changes in the values o the principal coils which have been found since the fir calibration in May 1952. The values of the 10 Ω coi have been determined in relation to a 10 Ω standard co (L.649) of N.P.L. manufacture which has shown no chang exceeding 1 in 10^6 since 1938. The 100 Ω coils are measure by comparing them with the sum of the 10 Ω coils and th 1000 Ω coils are then compared with the sum of the 100 coils.* A similar technique is followed for the lower-value coils of the bridge, and the ratio is finally determined b using the newly-calibrated bridge to measure L.649 and th special coils provided in the bridge itself. Since the heatin effect of the measuring current in the standard coils negligible (see below), a current of 2 mA is used in th measurement of the ratio in order to obtain high sensitivity

---

* With the circuit proposed by Gautier, the value of L_{max} is increased by a factor of $\sqrt{2}$, and da becomes 0·01 L_{max}: that is to say, if advantage is to be taken of the higher value of L_{max}, a must be more accurately adjusted.

* In calibrating the tenth coil of each decade, allowance mu be made for the resistance of the copper rod which connects th coil to the eleventh stud of the dial. This is not included in th resistance when the bridge is in normal use, but it is included duri calibration with a potentiometer.

Some idea of the consistency of calibration of the different decades may be obtained from a study of the determinations of the bridge ratio by the measurement of standard coils. In a typical case, two coils of value slightly in excess of 100·01 Ω were measured by using the four possible combinations of the first four decades of the bridge, 9–9–9–11, 9–9–10–1, 9–10–0–1 and 10–0–0–1. On each coil, the four esults obtained were in agreement to ±2 in 10^8, equivalent to ±0·02 of one stud on the last decade of the bridge. Measurenents on coils of 10·01 ohm using the three possible comoinations of decades (0–9–9–11, 0–9–10–1 and 0–10–0–1) igreed to ±2 in 10^7, also equivalent to ±0·02 of one stud on the last decade.

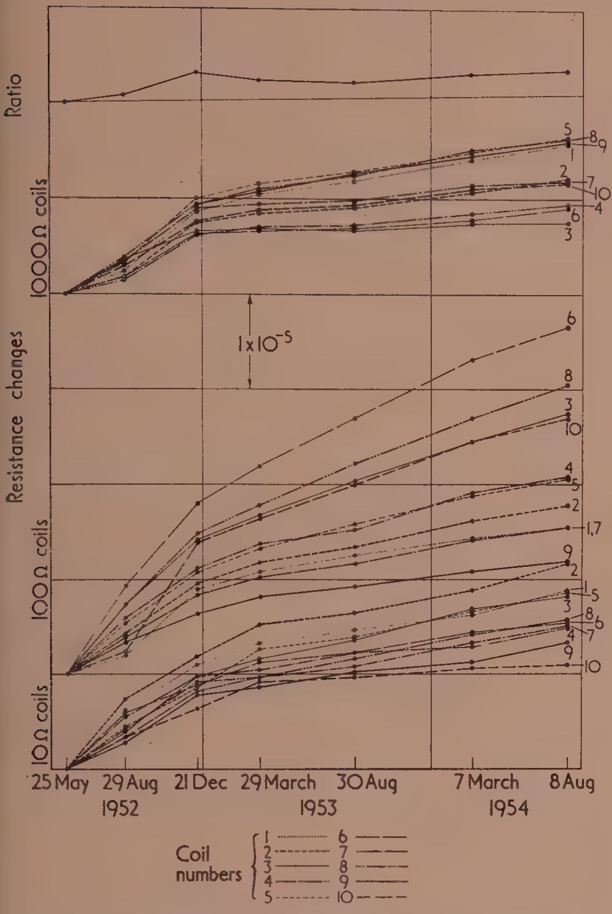


Fig. 12. Changes in resistance of bridge coils with time

It appears from Fig. 12 that the calibration of December 952 was probably in error by about 1 in 10^6, for the value of he ratio appears higher than would have been expected rom the general run of the curve, while there are corresponding humps on the curves of the 1000 Ω coils. That is o say, there was probably an error in the measurement of he Q arm of the bridge which has been corrected in the letermination of the ratio. The values found for coils 1 nd 10 in the 100 Ω decade in the calibration of August 1952 lso appear to be anomalous.

When the 1000 Ω coils were first completed, in the early nonths of 1951, their values were rising at the rate of about in 10^6 per month.$^{(4)}$ Fig. 12 shows that a year later, on he average, the corresponding rise was rather less than 1 in 10^6, by the spring of 1953 the rise was down to about 3 in 10^7 per month and somewhat less a year later. The seal round one of the leads of 1000 Ω coil No. 2 was broken and re-made (but without replacing the nitrogen atmosphere) during the construction of the bridge. This coil assembly, therefore, must contain a considerable amount of oxygen. It is noteworthy that its constancy is just about the average for the whole range of 1000 Ω coils, thus suggesting that nitrogen-filling is not essential.

It is interesting that the constancy of the 100 Ω coils is not nearly as good. They were made from the same wire and by the same method as the 1000 Ω coils: indeed, one of the latter was cut up to make ten 100 Ω coils. In the course of manufacture, however, about 1 cm of each end of each coil is pulled out straight before it is soldered to the copper lead. This is done after the annealing at 550° C, but before the final heat treatment at 120° C. The length in question amounts to about 1/2000 of the total length of a 1000 Ω coil and 1/200 of the length of a 100 Ω coil, and it seems likely that a good deal of the change in resistance takes place in this strained portion of the wire. Slight differences in the handling of these ends would then account for the big differences in constancy of apparently similar coils (Nos. 6 and 9 in the 100 Ω series, for example). The stability of the 10 Ω coils is nearly, but not quite as good as that of the 1000 Ω coils: the length of wire used is much less, but the wire is a good deal more robust.

The changes in calibration which took place in the first three months and then in two subsequent years are summarized in the table. The changes in QR/S, the measure of resistance, are very small, a fact which is emphasized if we calculate the errors which would have been introduced had the original calibration of the bridge been used at all times. Let us assume that we have a thermometer of 10 Ω fundamental interval and that we measured R_0, R_{100}/R_0 and $R_{444\cdot6}/R_0$ in May 1952. Subsequently we will take the value of R_0 as measured on the bridge at the time, but retain the original values for the ratios. Provided that the thermometer itself remained constant, we should, by August 1954, have observed an apparent fall of about 0·004° C in the ice point, but, when account had been taken of this, no temperature would have been in error by more than 0·001° C.

The temperature coefficients of the coils vary from 3 to 7 parts per million at 27° C. These values would have been higher had the coils not been pickled after the high-temperature vacuum annealing, which results in a copper-rich layer at the surface of the wire. It is interesting to correlate temperature coefficient with the extent of the pickling, as measured by the increase of resistance which it produced. Coils in which this increase lay between 4 and 6% showed temperature coefficients in the range 4 to 7 in 10^6 per °C, while all those in which the resistance increase lay between 6 and 11·5% had coefficients of either 3 or 4. It seems, therefore, that, with our conditions of annealing, pickling should be continued until the resistance has increased by at least 6%.

Errors due to self-heating of the bridge coils have been shown to be negligible in ordinary use. A current of 10 mA in the 100 Ω coils causes a rise in resistance of 3 in 10^7. A current of this magnitude is used in the calibration of the 100 Ω decade, and the necessary correction is made; but in use, the current in the Q arm never exceeds 2 mA. It is probable that the heating effect in the 1000 Ω coils would be slightly greater, since one 1000 Ω coil occupies the space of only two 100 Ω coils, but the heating effect could hardly exceed 1 in 10^7 for a current of 2 mA.

Summary of calibration changes, 25 May, 1952, to 8 August, 1954

Period	S/R	Change in parts per million					
		Q			QR/S		
		10 × 1 000	10 × 100	10 × 10	10 × 1 000	10 × 100	10 × 10
3 months, 25.5.52/29.8.52	+1	+3	+6	+5	+2	+5	+4
12 months, 29.8.52/30.8.53	2	7	11	7	5	9	5
11 months, 30.8.53/ 8.8.54	1	3	6	4	2	5	3

As well as the need for high stability in the values of the bridge coils, it is also essential that the zero resistance of the bridge should not be liable to erratic variations, and desirable that it should remain constant over long periods of time. Fig. 13 shows the results of an experiment carried out in October 1953 after the bridge had been in service for 18 months without any attention to the switches, which had been lubricated initially with Elvolube (by Gulf Oil Co.). At the start of the experiment the contacts had been left undisturbed for a considerable time, and the resistance of the Q arm was found to be nearly 0·0008 Ω (equivalent to 0·00008° C with a thermometer of 10 Ω fundamental interval) above its normal value. Thirty operations of all the switches (sweeping the contact from 0 to 10 and back thirty times) reduced the bridge zero to within the equivalent of two millionths of a degree of its normal, and this value was maintained for 36 hours with the switches undisturbed. A single operation of the switches, so as to disturb the surfaces without doing appreciable cleaning, caused the resistance to rise by 0·0002 Ω (0·00002° C). After rest periods varying from 5 to 15 h a similar effect, but of slightly less magnitude, was observed, while after $1\frac{1}{2}$ h at rest the rise was about 0·0001 Ω. In each case, operation of the switches twenty times brought the resistance down to its normal value. We have therefore made it our standard practice to give all the switches twenty operations at the start of each day's work.

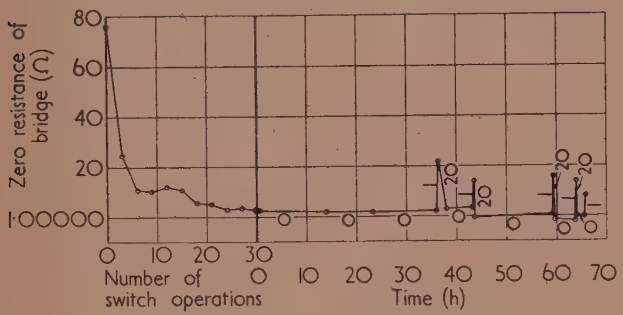


Fig. 13. Constancy of zero of Q arm. The figures on the curve give numbers of switch operations

CONCLUSIONS

The present bridge has enabled us to achieve our aim of making resistance thermometer measurements reproducible (under suitable conditions) to 0·0001° C. Nevertheless, we should prefer to make some modifications in any bridges that may be constructed in the future.

(i) We should prefer to use the circuit as modified by Gautier.(3) This would not only make it much easier to adjust the bridge, but, by suitably pairing the coils, the Q and a arms could be made to match very closely indeed.

(ii) The present design of coil and switch assembly (Fig. 3) is not ideal, as the accessibility of the a switches for cleaning is not good. It would be preferable to bring all switches to the upper end of the coil bank. This would involve placing the studs on a larger radius, with consequent stiffer movement of the switch, but this could be overcome to some extent by using single-brush switches in the a arm (see an earlier section on the general features of the bridge).

(iii) The main object of using a Perspex panel for the bridge was to enable the user to see whether the spinning air-distributors were revolving. Now that these have been abandoned, a metal panel could be used, and would, indeed, offer some advantage by eliminating risk of electrostatic effects. With Perspex, cleaning with an anti-static polish is occasionally necessary.

(iv) In order to avoid the need for water-cooling, it would be preferable to mount the fan motor outside the bridge structure.

ACKNOWLEDGEMENTS

The work described in this paper was undertaken as part of the research programme of the National Physical Laboratory and is published by permission of the Director of the Laboratory. The authors wish to acknowledge the help they have received from discussions with Mr. D. C. Gall and members of the staff of H. Tinsley and Co. Ltd., and from the careful work of the staff of the N.P.L. Instrument Workshop. Mr. L. H. Pemberton helped in the annealing of the coils and Miss V. M. Leaver in the experiments on the mock-up of the bridge and in the calibrations of the completed instrument.

REFERENCES

(1) SMITH, F. E. *Phil. Mag.*, **24**, p. 541 (1912).
(2) HALL, J. A., and BARBER, C. R. *Brit. J. Appl. Phys.*, **1**
p. 81 (1950).
(3) GAUTIER, M. *J. Sci. Instrum.*, **30**, p. 381 (1953).
(4) BARBER, C. R., GRIDLEY, A., and HALL, J. A. *J. Sci*
Instrum., **29**, p. 65 (1952).
(5) British Patent 616 684, June 1949.
(6) SEARS, J. E., and BARRELL, H. *Phil. Trans A*, **231**, p. 7
(1932).
(7) PRESTON, J. S. *J. Sci. Instrum.*, **23**, p. 173 (1946).

A demountable vacuum system for secondary emission studies

By A. Lempicki, M.Sc., A.R.C.S., A.Inst.P.*, Electronic Tubes Ltd., High Wycombe, Bucks

[*Paper received* 12 *January*, 1955]

A demountable vacuum system is described in which secondary emission measurements can be carried out without target contamination produced by electron bombardment. This all glass system is free of rubber, grease and wax joints and can be baked at 300–400° C.

t has become increasingly clear in recent years that all xperiments which depend critically upon the cleanness of urfaces bombarded by electrons (or emitting electrons) must e carried out in sealed-off glass tubes. The metal electrodes nd the target should be well outgassed by eddy-current eating and the glass envelope thoroughly baked.

This procedure, although well suited for many experiments, s rather troublesome when the need occurs for frequent hange of target or when chances of destroying the target luring the pumping process are large. Here a demountable acuum system has its obvious advantages being faster, more lexible and cheaper. Unfortunately the phenomenon of lectron bombardment contamination renders results obtained n kinetic vacuum system very unreliable and sometimes ompletely wrong.(1) Electron bombardment contamination ias been investigated by Ennos(2,3) and its sources traced o the presence of organic vapours in the system. These bnoxious vapours originate chiefly from the rubber or grease joints and from the glass walls and metal parts which annot be subjected to baking and eddy-current heating.

The advantages of a demountable vacuum system were learly recognized at the beginning of a series of rather pecialized secondary emission measurements. In point of act it seemed that sealed-off tubes were impractical for easons stated above. Considerable effort was therefore pent in developing a demountable system free of electron ombardment contamination.

CONTAMINATION IN ORDINARY DEMOUNTABLE SYSTEMS

There are several methods by which the effect of contaminaion can be measured. Probably the most direct is the one ised by Ennos who measured the thickness of carbonacious leposits formed when the electron beam strikes a target. For our purposes it was more expedient to use the measurenent of the secondary emission coefficient δ as an indication of the state of the surface. Since it is not possible to relate hanges of δ to variation of deposit thickness, the method ecessarily remains qualitative. We believe, however, that t is essentially more sensitive than the Ennos method, ecause contamination effects could be detected when no leposit was visible.

The secondary emission measurements were done by using a gun similar to a cathode-ray tube gun with electrostatic ocusing. The oxide cathode of the gun was shielded from he target during activation by means of a magneticallyperated shutter. The targets were made of 99·99% gold vhich was heated in vacuum to red heat prior to insertion in he apparatus.

The first experiments were carried out in a glass system oumped by a glass mercury pump with liquid air trap and perating at 5×10^{-6} mm of mercury.(4) (Hysil glass was ised throughout this work.) Four O-rings were used to eal the end plates and the trap. Eight vacuum terminals for lead connexions(5) were also used. Their presence and the bulkiness of the system prevented baking. Because of the geometry of the system the gun electrodes could not be eddy-current heated in position but had to be stoved in hydrogen prior to assembly. They were thus exposed to atmosphere and handling.

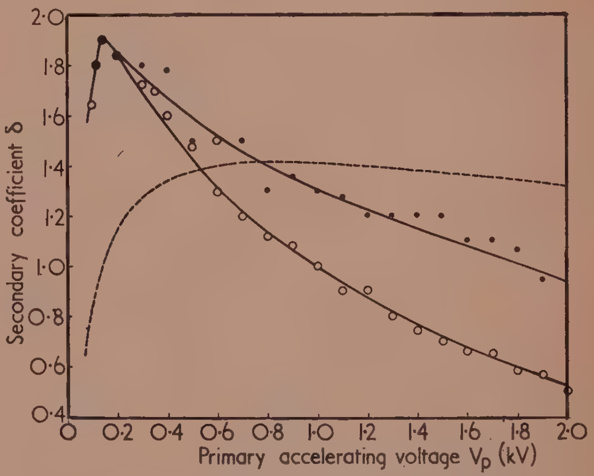


Fig. 1. Secondary emission of gold. Demountable system with four O-rings and eight terminals

● = initial results; ○ = after 30 min bombardment with 150 μA/cm²; – – – = sealed-off tube.

Fig. 1 gives the results of measurements of the secondary coefficient δ *versus* primary accelerating voltage V_p and its change after thirty minutes bombardment. An almost black stain produced by the beam could be seen on the target after removal from the apparatus. The dashed curve corresponds to the "true" secondary emission of a clean target, measured in a sealed-off tube which had been baked, eddy-current

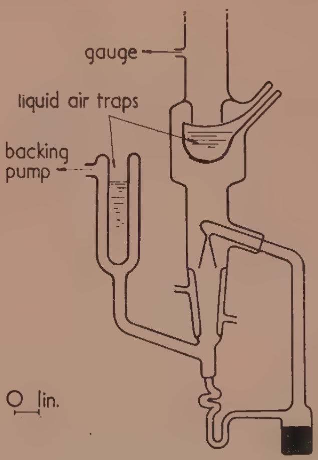


Fig. 2. Mercury diffusion pump (glass) with two liquid air traps.

---

* Now at Sylvania Electric Products Inc., Bayside L.I., New York, U.S.A.

heated and gettered. The striking difference between the two results could only be ascribed to very severe contamination of the target surface.

The first step towards reduction of this contamination involved the elimination of all terminals and of all O-rings except one. A vertical mercury pump with a spoon trap shown in Fig. 2 was used. A second liquid air trap was placed between the diffusion pump and the backing pump to prevent diffusion of oil vapour.(6) A head illustrated in Fig. 3(*a*) was sealed to the pump. This had on the tap a removable pinch sealed to the rest of the system by a single O-ring (of neoprene mix recommended by Ennos and boiled in caustic soda) held compressed between two flanges. A metal washer (not shown) prevented the O-ring from being sucked in.(5) The gun could be mounted vertically on the pinch. An eddy-current heater coil round the stem enabled the heating of the electrodes and target to be carried out. Because of the presence of the O-ring the system could not be baked but a light torching was possible. Attempts to clean the glass walls by a low pressure discharge were abandoned because of metal sputtering which produced troublesome electrical leakages in the gun. The operating pressure in this system was 10^{-6} mm of mercury. Fig. 4 represents some of the δ measurements obtained in this system. There is no doubt that a considerable improvement has been achieved. The shape of the δ curve is much more reminiscent of the "true" curve although large changes with time still occur. In a number of experiments carried out in this system the majority of targets showed light brown staining but some appeared almost clear. The heavy black deposit was certainly much reduced.

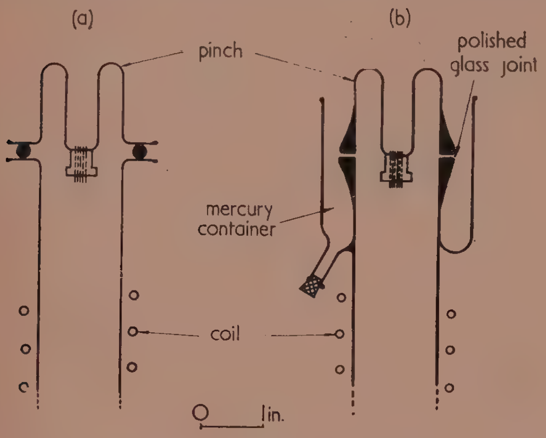


Fig. 3. Demountable heads

(*a*) With O-ring seal; (*b*) with polished glass seal.

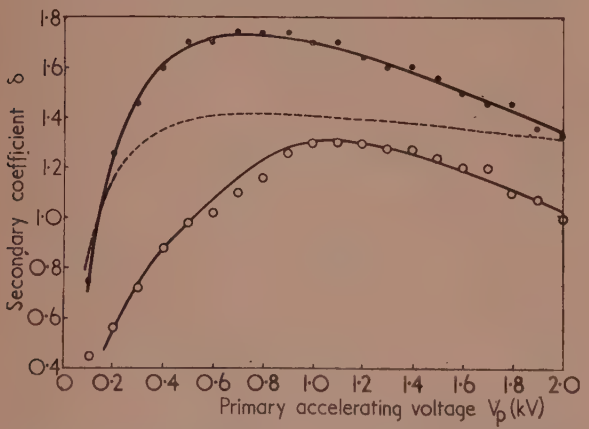


Fig. 4. Secondary emission of gold. Demountable system with one O-ring. Gun electrodes eddy-current-heated

● = initial results; ○ = after 30 min bombardment with 150 μA/cm^2; – – – = sealed-off tube.

NEW DEMOUNTABLE SYSTEM

It is evident that no demountable system can be rendered free from contamination unless it can receive all the heat treatment usually reserved for sealed-off devices. The essential next step in improving the system described in the previous section is to remove the rubber O-ring and bake the glass envelope. This was made possible by replacing the glass flanges of Fig. 3(*a*) by flat polished surfaces, as shown on Fig. 3(*b*). The ends of the glass stem and of the pinch were thickened to about 6 mm, ground and polished. The flatness of the surface was not specified to any accuracy, but from an observation of the interference colour pattern formed by the air film between the two surfaces, it was estimated that the flatness was approximately within six wavebands per inch which corresponds to a low quality optical flat. The glass surfaces must be very clean and free from dust before assembly. Taking even great care it is difficult to avoid scratches. Unless these are very severe they do not seem to be at all detrimental to the proper working of the seal. A clean pinch can easily be rotated under vacuum and a best position found by observing the gauge. Scratching may occur during this rotation but the grooves are circular and concentric with the seal annulus and thus produce no direct leak paths. The pressure which can easily be reached in this system is of the order of 10^{-4} mm of mercury. This is sufficiently low for baking the glass without causing oxidation of the electrodes and target. The whole head can be placed in an oven, reaching almost as far down as the liquid air trap and heated at any temperature up to, say, 400° C for any period of time. After cooling down, the glass container round the joint is filled with clean mercury. The pressure in the system drops to less that 10^{-6} mm of mercury in a few minutes. The gun can now be eddy-current heated, the oxide cathode activated and the secondary emission measured. Fig. 5 represents the results obtained in this system after two hours of baking. It is seen that no contamination is produced this time. An examination of the gold targets revealed no traces of staining after two hours bombardment.

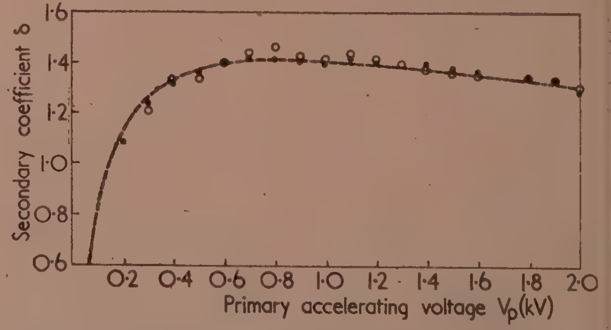


Fig. 5. Secondary emission of gold. Demountable system with polished glass seal. Baked two hours at 360° C, gun electrodes eddy-current-heated

● = initial results; ○ = after 90 min bombardment with 150 μA/cm^2; – – – = sealed-off tube.

CONCLUSIONS

The vacuum system described in the previous section ppears to provide a practical solution of the problem posed t the beginning of this paper. It is easy to manufacture n any laboratory having reasonable glass-blowing facilities. The polished joint presents no difficulties on account of the elatively low accuracy required. The system could have number of applications in fields other than secondary mission. Photoelectricity and thermionics are perhaps the nost obvious.

ACKNOWLEDGEMENTS

The author is indebted to Dr. C. S. Bull, Mr. D. A. Hockly nd Mr. E. Burgess for various helpful suggestions. The atter made all the glass work. Thanks are due to the Sunbury Motor Glass Co. for glass polishing and to Mr. B. Wilkinson, Managing Director of Electronic Tubes Ltd. for permission to publish this paper.

REFERENCES

(1) Lempicki, A., and McFarlane, A. B. *Nature* [*London*], **167**, p. 813 (1951).

(2) Ennos, A. E. *Brit. J. Appl. Phys.*, **4**, p. 101 (1953).

(3) Ennos, A. E. *Brit. J. Appl. Phys.*, **5**, p. 27 (1954).

(4) Lempicki, A. *M.Sc. Thesis* (University of London, 1952).

(5) Smith, J. R. W. *J. Sci. Instrum.*, **29**, p. 131 (1952).

(6) Blears, J. *J. Sci. Instrum. Supplement No.* 1, **28**, p. 36 (1951).

A photoelectric sampling switch for use in double-beam optical instruments

By D. M. Neale, B.Sc., A.C.G.I., A.M.I.E.E., Ilford Limited, Brentwood, Essex

[*Paper received* 24 *January*, 1955]

An electrometer circuit is described having high sensitivity, logarithmic response, negligible zero drift and requiring no "backing off." The two light beams are chopped at about 5 c/s and the 5 c/s output from the photocell amplifier is sampled by a simple photoelectric switch. Two cathode followers "memorize" the switch output between sampling intervals and provide on a microammeter a steady indication of the degree of unbalance of the two beams. The circuit is very simple to construct and maintain and does not require highly stabilized supplies.

he double-beam, null-balancing principle has found appliation in densitometers, spectrophotometers and a variety of ther optical instruments. It has the merit of greatly reducing ne effect of instability of the light source or photocell, withut introducing undesirable complications.

With such apparatus, the simple electrometer circuit of ig. 1 can be used as a highly sensitive null detector. It will e noted that the electrometer valve operates without any id leak. Consequently the grid potential is self-adjusting maintain equality between grid current and the photorrent of the vacuum cell. Since the grid current is an xponential function of the grid potential, the response of the rcuit is logarithmic over a wide range of light intensities. ence a given galvanometer deflexion corresponds always to e same proportional change in the light incident on the otocell.

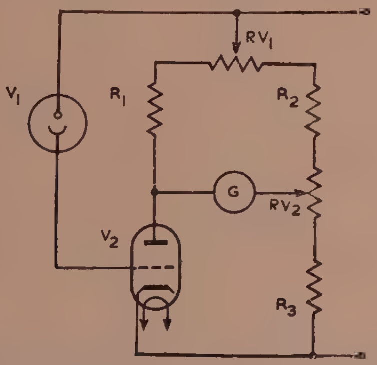


Fig. 1. Simple electrometer circuit with logarithmic response

Unfortunately, the success of this circuit is limited by instability of the galvanometer zero due to drifts in the supply potentials. One method$^{(1)}$ of overcoming this difficulty involves driving the beam-selecting shutter continuously and adjusting the beam balancing system until the galvanometer stops oscillating. In practice, however, it is often extremely difficult to design the shutter and optical system so that there is not even a temporary disturbance of the galvanometer each time the shutter moves from one beam to the other. Consequently, operation with any but a very short period galvanometer is made tedious by the necessity for allowing time for recovery from each transient.

SAMPLING AND STORING

By using a suitable sampling technique, the galvanometer can be made responsive only to the steady conditions obtained after the decay of each transient. Better still, the sampled deflexion is directly proportional to log I_1/I_2 where I_1 and I_2 are the intensities of the two light beams being compared.

Fig. 2 shows a simple circuit which will perform these functions. At the anode of V_2, a waveform appears of the type indicated in Fig. 3(*a*). It approximates to a rectangular wave when the instrument is considerably out of balance, but for a small degree of unbalance the disturbance produced by the shutter becomes appreciable, as shown here. The three-position switch S_1 operates according to the timing cycle shown in Fig. 3(*b*) to sample those parts of the anode waveform unaffected by the shutter disturbances. Thus the capacitor C_2 is charged to a potential governed by the intensity of one beam whilst the potential applied to C_3 depends on the intensity of the other beam. Provided the grid currents of V_{3a} and V_{3b} are negligible, the charges on C_2 and C_3 remain constant between one sampling period and the next. Provided the capacities of C_2 and C_3 are not made too large, however, the charge in each can be reset abruptly in a relatively short sampling period, as indicated in Figs. 3(*c*) and (*d*). A galvanometer or microammeter connected between the cathodes of V_{3a} and V_{3b} thus provides a direct indication of the degree of unbalance of the instrument. In theory, a continuous variation in the unbalance of the two beams will result in a microammeter deflexion changing by discrete increments at twice the frequency of shutter operation, as shown in Fig. 3(*e*).

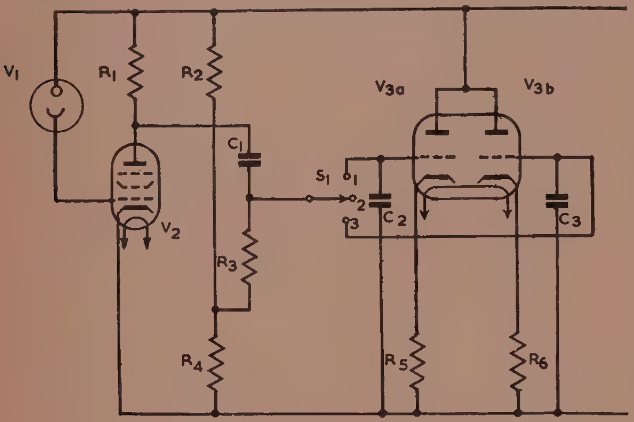


Fig. 2. Development of Fig. 1, with sampling and storage circuit used to improve stability and eliminate need for backing off

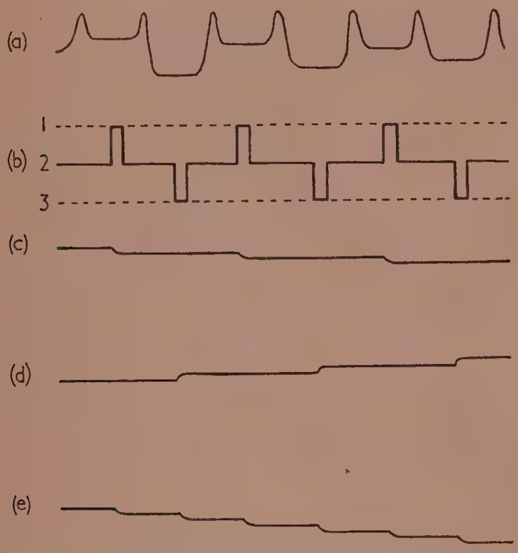


Fig. 3. Waveforms relating to circuit of Fig. 2

The sampling and storing feature of this circuit is closely similar to that used for the direct reading microdensitometer described by Tait and Chalklin.$^{(2)}$ The nature of the sampling switch and its speed of operation are different, however, and will be discussed in some detail.

SHUTTER SPEED

It is interesting to note that the majority of densitometers using continuously rotating shutters are designed for a chopping frequency of 50 c/s or more. This is most probably because amplifiers tuned to lower frequencies tend to become cumbersome. On other grounds, however, a low chopping frequency is advantageous. Maximum precision can be obtained by using a semi-circular shutter sector and yet the shutter need not rotate at high speed. The effects of hum pick-up and the light ripple in a mains-fed lamp can readily be filtered out if the chopping frequency is well below 50 c/s.

With these factors in mind, it was not disturbing to find that practical combinations of photocell and electrometer could not respond to chopping frequencies above about 10 c/s without producing waveform distortion at low light intensities. Hence, in an application such as a colour densitometer, where high sensitivity is required at low light intensities, it was considered desirable to use a chopping frequency well below 10 c/s. On the other hand, assuming an operator's personal response time to be of the order of 0·2 s, it was clear that speed of manual balancing would suffer if the chopping frequency was reduced much below 5 c/s. Accordingly, the shutter and switch have been designed for 5 c/s operation although practical tests have shown that only a very small zero shift is produced by increasing the speed to 25 c/s.

The optimum values of C_2 and C_3 were determined empirically. To some extent they depend on the damping of the meter used to indicate balance. If the capacities are too high the meter response is sluggish. If they are too low, some oscillation of the meter may be observed. In practice, both defects can be avoided quite readily.

With the circuit of Fig. 2, it is necessary to prevent hum components from reaching the sampling switch. If no such precautions are taken, the meter deflexion wavers rhythmically as the opening of the sampling switch moves in and out of phase with the peaks and troughs of the hum waveform. By using efficient screening and d.c. lamp and heater supplies this effect could no doubt be eliminated. In practice it is more convenient to use a.c. supplies and insert a three-section resistance-capacitance filter between the anode of V_2 and the sampling switch.

PHOTOELECTRIC SWITCHING

Although a mechanical sampling switch was used experimentally, its elimination was considered desirable to simplify maintenance. In its place, an electronic switch was required characterized by the following features:

(1) High ratio of off/on impedance; (2) low contact potential; (3) low rate of drift; (4) earth-free; (5) simple and reliable.

Only one device was known to meet these requirements. The photoconverter, described by MacMillan and Field,$^{(3}$ uses two vacuum photocells connected in parallel with reverse polarities. In the absence of light, the cells exhibit a very high impedance. When illuminated, their parallel impedance to small potentials falls to a fraction of a megohm. Operation of the switch may thus be effected by controlled light flashes either from a pulsed neon lamp or from a combination of lamp and shutter. With matched photocells, the contact potential is very low and a stability of better than 0·1 mV/h has been claimed.

Two pairs of vacuum photocells have been used for the sampling switch as shown in Fig. 4. The pairs are diametrically opposed about the centre of the shutter and the switching action is determined by an auxiliary sector at a greater radius than the semi-circular sector controlling the sample and comparison beams. Illumination of the cells could have been provided by the 48 W lamp already used in the instrument, but it proved more convenient to mount two flashlamp bulbs close to the shutter. These 6·5 V bulbs are run at 5 V to ensure long life. The photoelectric switch ppears to be in no way critical regarding the light intensity equired and the lamps are run on a.c. without ill-effect. Care has been taken, however, to ensure that both photocells n a pair are illuminated and obscured simultaneously.

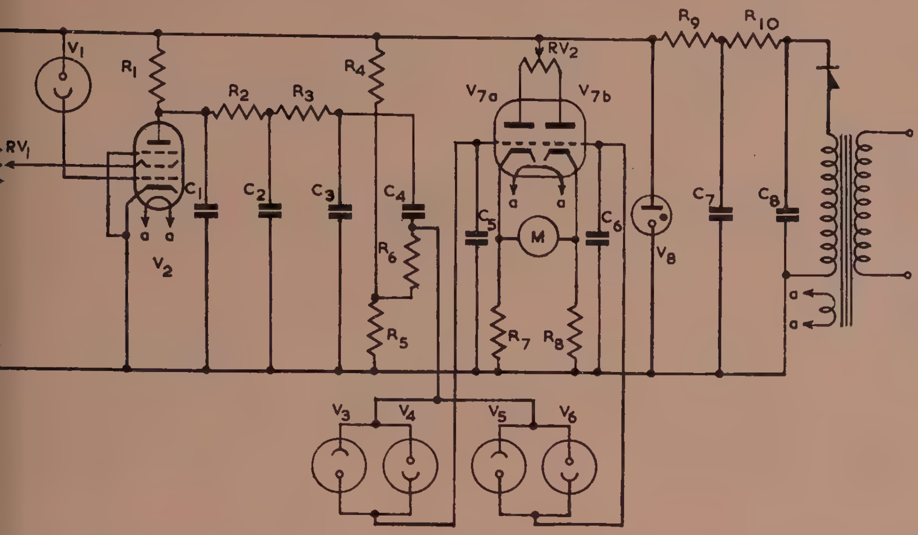


Fig. 4. Development of Fig. 2, with low-pass filter and photoelectric sampling switch

$R_1, R_2, R_3 = 33$ kΩ
$R_4; = 100$ kΩ
$R_5; = 10$ kΩ
$R_6; = 1$ MΩ
$R_7, R_8 = 10$ kΩ
$R_9; = 3 \cdot 3$ kΩ
$R_{10} = 5$ kΩ

$RV_1 = 100$ kΩ
$RV_2 = 10$ kΩ

$C_1, C_2, C_3 = 0 \cdot 1$ μF
$C_4 = 1$ μF
$C_5, C_6 = 0 \cdot 1$ μF
$C_7 = 100$ μF
$C_8 = 60$ μF

V_1 = VB32
V_2 = ME1400
V_3–V_6 = 90CV
V_7 = 6SN7
V_8 = 90C1

The shutter was turned from ⅛ in. Duralumin and much f the material was milled out to reduce weight and improve he balance. The full thickness was retained at the periphery o facilitate rim drive from a gramophone type induction otor. Fig. 5 shows the arrangement of the changeover and ampling sectors. To allow for the phase lag produced by

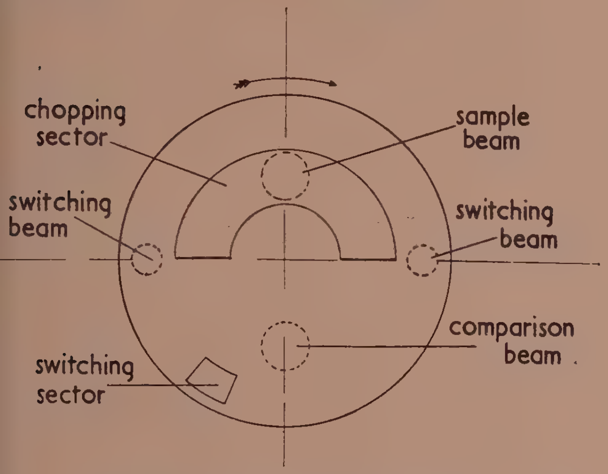


Fig. 5. Chopping shutter for double-beam instrument, showing auxiliary switching sector

e low-pass filter shown in Fig. 4, the sampling action is med to occur just before the beam changeover. This allows e maximum time for the decay of transients due to the evious changeover.

PERFORMANCE

Tests with the circuit of Fig. 2 showed that the instrument as capable of very high sensitivity. With a 50–0–50 μA meter, a full-scale deflexion was produced by an unbalance of ±0·035 density units. The circuit could thus have detected an unbalance of ±0·001 density units with ease, had the optics justified such precision.

For rapid routine work, the circuit of Fig. 4 has been modified by shunting the meter with a pair of crystal diodes connected with opposite polarities. The diodes affect the near-balance sensitivity of the instrument to but a small extent, but, after addition of some resistance in series with the meter, reduce the full-scale sensitivity so that an error of 1·5 density units is indicated by full-scale deflexion. Not only does this arrangement provide protection of the meter against overloads, but also it enables the operator to estimate immediately the extent of unbalance and so the amount by which the balancing wedge must be moved.

The circuit described has been used for some time in a colour densitometer. The narrow-cut colour filters in the sample beam necessarily reduce the light available and hence the sensitivity falls appreciably at high densities. Nevertheless, a uniform, high sensitivity is maintained up to a density of 2·8 and thereafter the gradual fall-off is such that a density of 4·0 can still be read to ±0·01 density units.

ACKNOWLEDGEMENTS

The author is indebted to the Directors of Ilford Limited for permission to publish this paper, to Mr. R. G. Horner for his encouragement and advice, and to Mr. E. A. Harvey who designed the mechanical and optical parts of the densitometer.

REFERENCES

(1) Dobson, G. M. B. *Proc. Roy. Soc. A*, **104**, p. 248 (1923).
(2) Tait, R. I., and Chalklin, F. C. *J. Sci. Instrum.*, **30**, p. 268 (1953).
(3) MacMillan, R. A., and Field, W. G. *Rev. Sci. Instrum.*, **24**, p. 984 (1953).

Apparatus for measuring the intensity of cosmic radiation at great depths in the sea

By J. C. Barton, B.Sc., Ph.D., Physics Department, University College of the West Indies, Jamaica

[*Paper received* 1 *December*, 1954]

A portable cosmic-ray equipment and an aluminium alloy pressure vessel in which it can be enclosed are described. The apparatus consists of a three-fold coincidence arrangement of Geiger–Müller counters operated entirely from dry batteries. The total power consumption is about $\frac{1}{4}$ W and one set of batteries is sufficient for a week's continuous operation. A small portable scaler which can be used in conjunction with this apparatus is also described.

One of the ways in which information can be obtained about the properties of mesons with extremely high energy is to measure the variation of the intensity of cosmic radiation below sea level. Many measurements have been made in mines but the interpretation of these results is doubtful because of uncertainties in the thickness and nature of the rock above the recording equipment. It is therefore preferable to make observations in the sea, and results have been obtained, at moderate depths, by Clay, Gemert and Clay.(1) The purpose of the work at present in progress is to obtain results down to a depth of at least 3000 m.

Because of the great difficulties which arise if power has to be supplied to the apparatus from a ship, through both the cost of the cable and the problem of leading it into the pressure vessel, it was decided that the apparatus should be entirely self-contained. The size of the apparatus was fixed at an early stage in the design. The weight of a pressure vessel of given shape increases as the cube of its linear size, and both the initial cost and difficulties of handling increase with the weight. It was therefore decided to choose a cylindrical vessel of 8 in. internal diameter and 36 in. maximum internal length. This provides sufficient space for a three-fold telescope with four standard counters, of diameter 3·8 cm and active length 60 cm, in each bank.

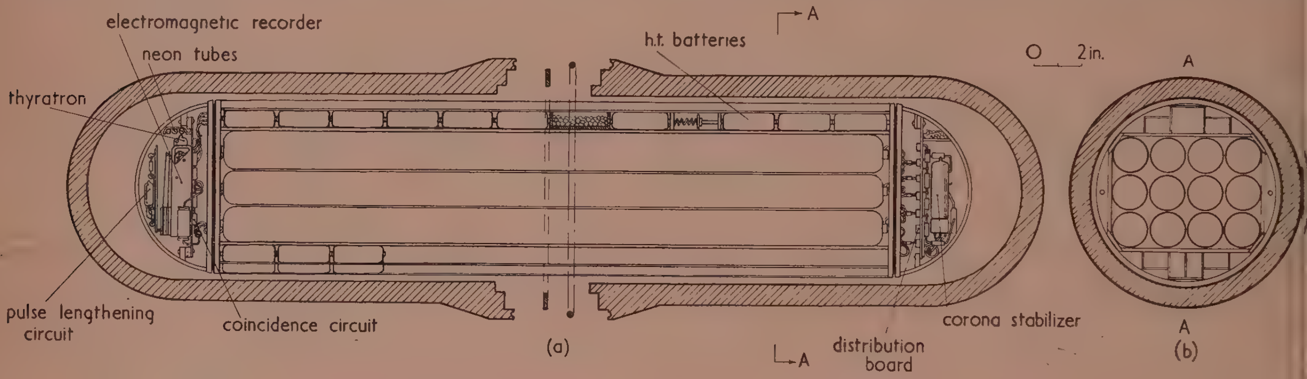


Fig. 1. Longitudinal (*a*) and transverse (*b*) cross-sections of recorder inside pressure vessel

PRESSURE VESSELS AND SEALS

Previous pressure vessels have invariably been constructed of steel or bronze but it was thought that lighter vessels might be possible using other materials. A quarter-scale vessel was made in Perspex and this was tested at the Chemical Research Laboratory under a pressure of 300 atm. This test was successful, though there were signs of internal cracking and "crazing." The idea was eventually abandoned because at present it is not feasible to manufacture Perspex in the large thickness which would be required for a full-size vessel.

Instead it was decided to use an aluminium alloy vessel. By choosing the shape shown in Fig. 1 the two halves could conveniently be forged, with greater resulting strength. Using Hiduminium 44 W.P. alloy (by High Duty Alloys Ltd. the vessels made are expected to withstand a hydrostati pressure of 400 atm, which is roughly equivalent to a dept of 4000 m in the sea. The complete pressure vessel weigh only 96 lb. (Compare the spherical bronze pressure vesse described by Arley, Lunn, Nielson and Nørgaard(2) of 50 cm internal diameter, capable of withstanding 1000 atm bu weighing 1·1 t.) The two halves are held together with a pair of aluminium clamping rings which are secured with eight $\frac{3}{8}$ in. bolts. The main pressure seal is made by a ring of rubber $\frac{3}{4}$ in. wide and $\frac{1}{8}$ in. thick, cut from soft rubbe sheet. The outer O-ring is used as an additional precaution particularly for fear that the main seal might leak at moderate pressures after being subjected to very great pressures. It was fabricated from $\frac{5}{16}$ in. diameter O-ring material.

COUNTER TELESCOPE

At first sight it might be thought that low-voltage counter of the halogen type would be particularly appropriate fo this work. Unfortunately, these counters often exhibi appreciable delays between the initiating event and the formation of the discharge, as has been shown in the work of Loosemore and Sharpe.(3) It would therefore be necessary to use a coincidence circuit of relatively long resolving time which would mean using a four-fold coincidence arrangemen if the accidental rate were to remain sufficiently small. It was therefore thought preferable to use a three-fold arrangement of conventional counters, despite the disadvantage of the higher voltage which their use entails. The total space required for counters and batteries is no larger, the counting rate higher and the cost less. Ethyl formate quenched counters, made by Cinema-Television Ltd., were chosen since it was necessary for the apparatus to function at temperature down to 0° C; their behaviour has been very satisfactory.

The supply for the counters must provide up to 1500 V with a current large enough for fluctuating leakage current to be unimportant. With careful design it was found possible to keep leakage currents down to less than 1 μA, so it wa hought that a steady current of 20 μA should be adequate. n order to stabilize the voltage a corona stabilizer is used. Iolton and Sharpe(4) have shown that, provided a condenser s placed in parallel, these tubes operate satisfactorily for a ninimum current of 15 μA.

Various methods were considered for supplying this high-oltage; supply units operating from a lower d.c. voltage have een described in the literature and others were tried. None f these had an efficiency greater than 50% (often much less) nd the output voltage always varied more rapidly than that f the battery supplying the unit. It was therefore decided hat an array of miniature batteries to provide the entire oltage would be the simplest and least troublesome solution. maximum negative voltage of 1200 V is obtained from a istribution board for the cathodes of the counters and the nodes returned to a positive voltage of 240 V.

COINCIDENCE AND RECORDING CIRCUITS

A crystal coincidence circuit of the type described by Chen(5) and Elmore(6) was used to give a short resolving time vith minimum consumption of power. It is followed by an dditional crystal acting as a discriminator. It will be noted hat a small value, 3 V, is chosen for the supply voltage to his circuit. It was found that this was an advantage as ven a small counter pulse was sufficient to give the standard utput pulse; this is not maintained when the differentiated ounter pulse is less than the supply voltage. The circuit alues provide a time constant of 3 μs which leads to an bserved resolving time of about 5 μs. Germanium point-ontact crystal rectifiers, type GEX 45/1 (by The General Electric Co. Ltd.), were selected both for adequately high ack resistance, particularly for the discriminator, and correct operation under pulse conditions; some specimens showed spurious effects, possibly due to the "hole storage" phenomenon.

The problem of operating the standard Post Office electromechanical counter is one of conserving power without sacrificing reliable operation. Any type of hot-cathode thyratron is clearly excluded and the only available cold-cathode valve which will pass sufficient current is the type Z300 T(1267). This was found in practice to satisfy the requirements provided:

(i) the limiting values were carefully observed;
(ii) the cathode was illuminated;
(iii) the triggering pulse was sufficiently long.

In operation, the cathode is illuminated by placing three sub-miniature neon tubes over the end of the type Z300 T valve. These also provide a stabilized positive voltage for the counters, so the small power consumed is not wasted. It will be seen from Fig. 2 that the triggering bias voltage is made a constant fraction of the anode voltage. This arrangement was found preferable to stabilizing the trigger voltage as it prevented the circuit from "jamming" at high counting rates. Although some illumination is essential for reliable operation it should be noted that very intense light with a high ultraviolet content may lead to instability. The coincidence pulse from the discriminator is only of one volt amplitude and a few microseconds duration which makes a pulse lengthening stage necessary. A univibrator circuit was developed using two sub-miniature pentodes, type CV 385 being chosen because these valves happened to be readily and cheaply available. To avoid the necessity of stabilizing all the voltages, the idea in the circuit developed by Cooke-

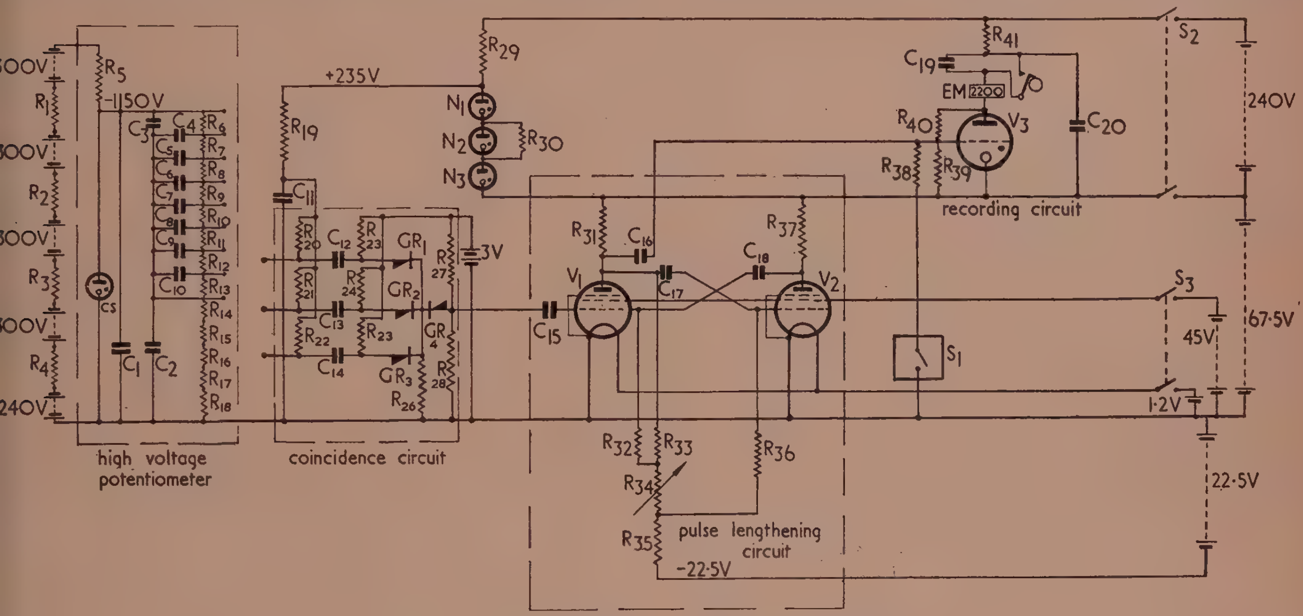


Fig. 2. Circuit diagram of cosmic-ray recorder

R_1–R_4 = 470 kΩ
R_5 = 1 MΩ
R_6–R_{13} = 1·5 MΩ
R_{14}–R_{18} = 8·2 MΩ
R_{19} = 1 MΩ
R_{20}, R_{21}, R_{22} = 560 kΩ
R_{23}, R_{24}, R_{25} = 10 kΩ
R_{26}, R_{27}, R_{28} = 100 kΩ
R_{29} = 1 MΩ
R_{30} = 10 MΩ
R_{31} = 68 kΩ

R_{32} = 2·2 MΩ
R_{33}, R_{34}, R_{35} = 1 MΩ
R_{36} = 470 kΩ
R_{37} = 68 kΩ
R_{38}, R_{39} = 2·2 MΩ
R_{40} = 5 MΩ
R_{41} = 20 kΩ

C_1 = 460 pF
C_2–C_{11} = 0·01 μF
C_{12}, C_{13}, C_{14} = 300 pF

C_{15} = 100 pF
C_{16} = 0·01 μF
C_{17} = 25 pF
C_{18} = 300 pF
C_{19} = 0·01 μF
C_{20} = 8 μF

V_1, V_2 = CV385
V_3 = Z300T

N_1, N_2, N_3 = NT2

CS = Corona stabilizer

EM = electromagnetic counter (2·2 kΩ)

GR$_1$–*GR*$_4$ = GEX45/1

S_1 = time switch
S_2 = double-pole single-throw toggle
S_3 = double-pole single-throw toggle

Yarborough, Florida and Davey(7) was used to fix the triggering sensitivity. Only one pre-set control is provided and even this only needs to be adjusted initially. The circuit operates correctly if the applied voltages are in the range from +5% to −15% of the design values.

A time switch, adapted from an eight-day bomb delay mechanism, enables the recorder to be operative only when required. The arrangement shown in Fig. 2 prevents spurious counts on switching.

LAY-OUT OF COMPONENTS

The various parts of the equipment are contained in a Perspex case. The batteries are housed in the individually sealed sections above and below the counters; access to the battery boxes is obtained through removable hatches which can be secured with Lassovic tape (by Herts Pharmaceuticals Ltd.). The high-voltage supplies are provided by linear arrays of hearing-aid batteries, Ever Ready type B 123. A spring spacer and a silica gel container are included in each section. The upper central box is of a larger cross-section than the others and contains the higher capacity batteries for the pulse lengthening circuit, including four type R.M. 4 cells (by Mallory Battery Co.) in parallel for the valve filaments. It has been found that battery performance is perfectly satisfactory, even under tropical conditions, provided that the silica gel is replaced when necessary.

One of the two hemispherical Perspex ends contains the counter voltage supply circuits and the other the recording circuits. The former has a voltage distribution board so that the individual counter voltages may be adjusted; it is made of aluminium strips mounted on polystyrene to minimize leakage. In the other end are the coincidence and pulse lengthening circuits, switches, time switch, cold-cathode tube and Post Office counter; the circuits are mounted on individual pieces of paxolin so that they may be replaced by spares if servicing is necessary. The whole assembly is attached to the hemisphere by means of sponge rubber mounts. The ends are each secured to the centre part by six screws and the joins sealed with O-rings. This method of construction has proved very satisfactory; the Perspex cases are strong, provide excellent electrical insulation and give complete protection against rain or spray. A small amoun of silica gel inside the cases ensures that no trouble is cause by moisture condensing when the temperature falls.

MINIATURE SCALER

The maximum counting rate of the recording circui described above is only about 2 counts/s, whereas the se level rate of three-fold coincidences is about 10 counts/s It is therefore necessary to include a scaler, if measurement are to be made on land or at small depths in water. Th scaler, the circuit of which is given in Fig. 3, has been designe so that it can be placed inside the Perspex case if one counte is removed from each layer. In fact, measurements of thi type suggested have not yet been made, but the scaler ha proved extremely useful for testing the whole equipmen before and after observations. The circuit is not fundamentally novel though care has again been taken to reduc the battery current to a minimum; the steady current drai is 0·5 mA when the circuit is not counting. This unit i built in a Perspex box 14 × 4½ × 1½ in., the rear portion o which contains the sixteen B 123 batteries from which i operates.

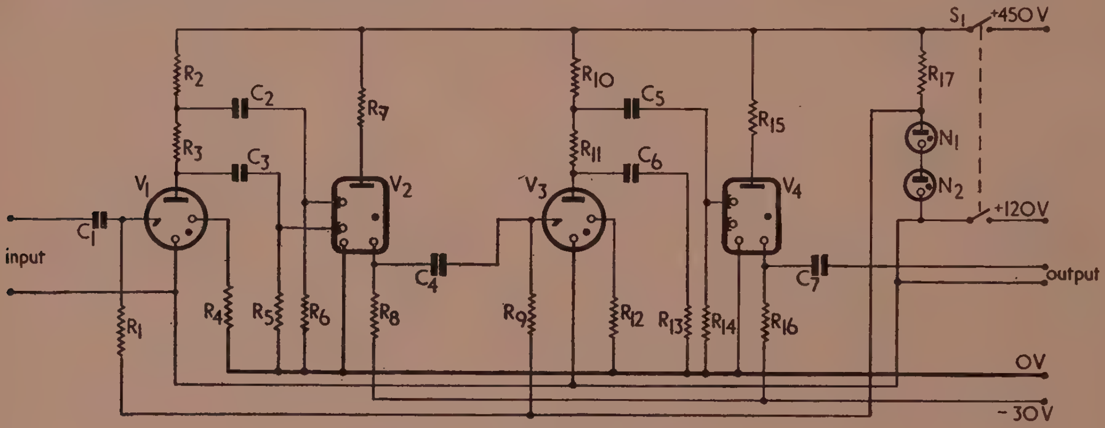


Fig. 3. Circuit diagram of scaler

R_1 = 1·2 MΩ
R_2 = 390 kΩ
R_3 = 68 kΩ
R_4 = 8·2 MΩ
R_5 = 200 kΩ
R_6 = 390 kΩ
R_7 = 2·2 MΩ
R_8 = 470 kΩ
R_9 = 0·5 MΩ

R_{10} = 390 kΩ
R_{11} = 68 kΩ
R_{12} = 10 MΩ
R_{13} = 200 kΩ
R_{14} = 390 kΩ
R_{15} = 2·2 MΩ
R_{16} = 470 kΩ
R_{17} = 700 kΩ

C_1 = 0·001 μF
C_2 = 0·003 μF
C_3 = 0·002 μF
C_4 = 0·001 μF
C_5 = 0·01 μF
C_6 = 0·005 μF
C_7 = 0·01 μF

V_1 = Ericsson GTE175M
V_2 = Ericsson GC10M
V_3 = Ericsson GTE175M
V_4 = Ericsson GC10M
N_1, N_2 = Ericsson GD86W

S_1 = double-pole single-throw toggle

OPERATIONAL EXPERIENCE

In the laboratory, at a temperature of 25° C, the whole apparatus operates from one set of batteries for at least a week. At low temperatures the battery performance is poorer, but at least three days operation is possible at 0° C. The total power consumed is about ¼ W, of which 100 mW is used for the e.h.t., 80 mW for the various h.t. supplies and 50 mW for the filaments.

During August 1954, the opportunity was given to try out the complete equipment on R.R.S. *Discovery II* in the Bay of Biscay. The pressure vessels proved entirely satisfactory and the recording equipment required very little attention. On one occasion the apparatus was at a depth of 3000 m for three days and there was no trace of leakage; even the space between the two rubber seals remained dry. Unfortunately, the technique for maintaining the apparatus at a constant depth was unsatisfactory owing to the prevailing bad weather, so that the results obtained are not yet reliable.

is hoped that a further attempt will be possible at a later ite.

In general the apparatus described has met the requirements tlined above. From the experience gained it is clear that rther reductions in the power consumed are possible and at these would be worth while. The least satisfactory ature of the equipment was the need to lower and raise it times previously selected on the time switch, which did not ways meet the exigencies of operations at sea. Some sort continuous recording would undoubtedly be preferable d ways of achieving this are now being explored.

ACKNOWLEDGEMENTS

Mr. LeVie of the Aluminium Development Association ggested the basic design for the pressure vessels. Mr. . A. Yardley carried out the tests on the Perspex model at e Chemical Research Laboratory. Dr. G. E. R. Deacon, irector of the National Institute of Oceanography, enabled e operational tests to be made part of the Institute's proramme. The personnel of both the Institute and of R.R.S. *iscovery II* carried out these tests with great skill, often nder difficult conditions. The capital cost of the equipment was provided by the University of London Central Research Fund. The recording equipment was built in the physics department of the University College of the West Indies, with the skilled assistance of the technical staff. Of the many others who have contributed their encouragement, assistance or advice, Dr. E. G. Michaelis has been outstandingly helpful, and co-operated in the final tests.

REFERENCES

(1) Clay, P. H., Gemert, A. V., and Clay, J. *Physica*, **6**, p. 184 (1939).
(2) Arley, N., Lunn, B., Nielson, M., and Nørgaard, C. *Nature* [*London*], **171**, p. 383 (1953).
(3) Loosemore, W. R., and Sharpe, J. *Nature* [*London*], **167**, p. 600 (1951).
(4) Holton, P., and Sharpe, J. *Electronic Engng*, **25**, p. 63 (1953).
(5) Chen, T. C. *Proc. Inst. Radio Engrs*, **38**, p. 511 (1950).
(6) Elmore, W. C. *Rev. Sci. Instrum.*, **21**, p. 649 (1950).
(7) Cooke-Yarborough, E. H., Florida, C. D., and Davey, C. N. *J. Sci. Instrum.*, **26**, p. 124 (1949).

A high-temperature, X-ray diffraction, powder camera

By E. Matuyama, Ph.D., Faculty of Engineering, Yamaguchi University, Ube, Japan

[*Paper received* 23 *November*, 1954]

A high-temperature Debye–Scherrer camera fitted with a small carbon-tube furnace, which is capable of attaining temperatures as high as 1800° C, is described. The furnace is housed in an evacuated cylinder having a slot covered with an aluminium foil. The scattered X-rays pass through the foil and impinge on a photographic film 20 cm in diameter. The camera records a comparison pattern on a film. The coefficients of thermal expansion of the Ceylon graphite determined with the camera are $0\cdot95 \times 10^{-6}$ and $28\cdot09 \times 10^{-6}$ respectively for *a*- and *c*-dimensions in the temperature range 1000–1800° C.

number of high-temperature, X-ray diffraction, powder meras, used for studying phase changes, thermal expansion crystals and effects of thermal motion have been described, d some of them are available commercially. Various types furnace for use with the camera have also been reported.(1,2) ost of these furnaces employ metals, especially platinum, a heating element. Higher temperatures may be attained ith a carbon tube instead of metals. A high-temperature ebye–Scherrer camera, 20 cm in diameter, and capable of taining diffraction patterns of Ceylon graphite in the mperature range from 1000 to 1800° C has been constructed d is described below. Since the object of most cameras this type is to find some changes occurring in the sample ystals at high temperatures, this camera has been conructed so that two diffraction patterns of different teneratures may be recorded on a photographic film. Thus rors due to the shrinkage of film and mounting a film on a m holder are eliminated. The furnace temperature was irly stable over many hours.

The accurate measurements on the thermal expansion of the tural graphite from room temperature to 800° C were ade by Nelson and Riley(3) and discussed thermonamically.(4) Walker, McKinstry and Wright(5) measured e thermal expansion of *c*-dimension with a graphitized rbon in the temperature range −196 to 1118° C and termined the effect of different atmospheres on the expanon of the crystal in the direction normal to the basal plane. e camera described below is capable of extending the temperature range and larger shifts of the diffraction lines could be expected with it. The expansion coefficient of *a*-dimension, corresponding to the strong covalent linkage of carbon–carbon atoms, is much smaller than that of the *c*-dimension, corresponding to loose bonding between the layer planes by the van der Waals-type force, by a factor of about 1/28 and, in the case of Nelson and Riley, the shifts measured were only slightly above the experimental errors. At 1800° C, a clear and definite shift has been photographed with this camera.

CONSTRUCTION

The construction details of the camera are shown in Fig. 1. The carbon tube is clamped with close-fitting copper plates to copper electrodes 17 mm in diameter, through which an electric current is passed; the heat evolved at the terminals is conducted to the upper water-cooled copper plate. Siemens arc carbon was used. This carbon is homogeneous and has little ash content; after using this carbon there was no observable deposit within the housing, although some other carbons deposited white powder. The carbon tube is 6 cm in length, 6 mm in diameter and 3 mm in bore. Both ends of the tube are electroplated with copper to ensure good electrical contact with the electrodes, the inner surfaces of which are ground so as to fit well on the tube. The collimated incident X-rays enter from one end of the tube and pass through it without striking the inner surface. A specimen rod 0·5 mm in diameter is inserted vertically in the middle of the tube through a drilled hole providing a sliding fit. The X-rays scattered from the specimen pass through a horizontal slot 1 mm in breadth, the upper edge of which is slightly cut down at the central portion of the carbon tube to allow light to pass to the optical pyrometer. A cylinder of nickel plate wound on a fused-silica tube 2 cm in diameter is attached around the carbon tube for use as a radiation shield, but up to 1300° C it has not been needed. Fig. 1(*b*) shows the construction of the camera. The carbon tube i supported horizontally in the evacuated cylinder (10 cm i diameter with walls 6 mm thick) a copper tubing bein soldered for water-cooling on the internal surface. On thi cylinder a collimating tube for the incident beam is fitte the first slit of the tube being covered with an air-tigh transparent film. On the opposite side of the collimatin tube is a tube for centring the specimen and for alining i with the X-ray beam. On the front of the cylinder is a slo 2 mm in breadth for transmitting the scattered rays fro 5 to 85° of Bragg angle. On the slot an aluminium fo 0·01 mm in thickness is cemented with glyptal, which withstands the atmospheric pressure and the heat radiated fro the furnace. A tube 2 cm in diameter, for the use of optica pyrometry, is inclined at an angle of 20° and situated 25° t the left side from the centre of the slot. An iron shutter i provided behind the glass window attached at the end of th tube, which is operated magnetically from outside an prevents any fogging on the glass. On the back of the cylinde is a pipe 2 cm in diameter for use when evacuating with a oil diffusion pump. On the top of the cylinder is a flange the upper surface being ground flat. A heavy circular plat of copper rests on the flange to which is applied suitabl grease. This copper plate, 7 mm thick, is water-cooled b two loops of copper tubing soldered on the upper surface and the electrodes and the furnace are attached beneath i One of the copper electrodes is directly soldered on the plat and the other one is fixed by a screw insulated with mic washers. The plate is centred by four guide blocks fixe on the flange and, once adjusted, the plate may be place again in exactly the same position. The semi-circular photographic film holder, 20 cm in diameter, is mounted by mean of a tripod on a steel baseplate, 12 mm thick, which is fitte with four levelling screws. The film is supported tightly o the inner surface of the holder by an expansion of a slightl bent thin Bakelite plate inserted on one side of the film Between the aluminium window and the film a brass plate i placed which has a slit 3·5 mm in breadth and which cover one half of the film. By changing the slit, the other ha may be exposed and thus the two diffraction patterns to b compared are recorded on the same film. A brass cover o the film holder (not shown) protects the photographic film from light and stray X-rays.

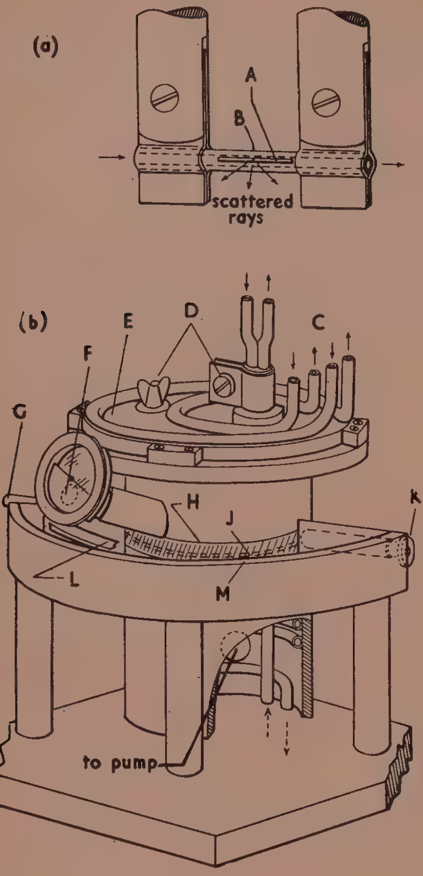


Fig. 1 (*a*) The carbon-tube furnace
(*b*) The high-temperature camera

A, slot in carbon tube; *B*, specimen; *C*, cooling water; *D*, heating current; *E*, ground copper plate; *F*, window for pyrometry; *G*, collimator; *H*, aluminium foil; *J*, slot; *K*, for centring; *L*, interchangeable slit for exposing; *M*, film holder.

RESULTS

The power consumption of the furnace was 450 W a 1800° C. The heating current was supplied by a 2·5 kW 100 V voltage stabilizer and the voltage was regulated with variable transformer and in turn dropped with a step-dow

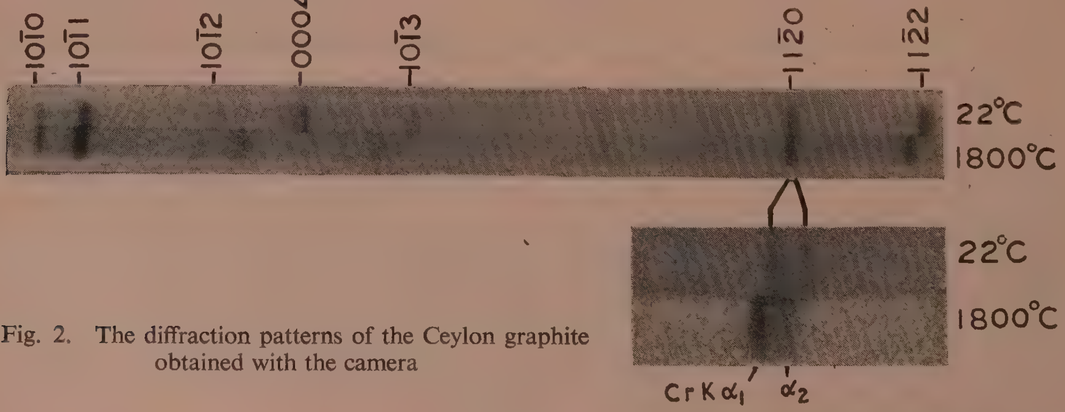


Fig. 2. The diffraction patterns of the Ceylon graphite obtained with the camera

ansformer of ratio 1 : 10. In the primary circuit of this ow-voltage transformer a resistance of 2 Ω was inserted to inimize the effect of resistance change in the carbon tube. fter several hours of burning, the furnace temperature ad remained sufficiently constant over the entire exposure me of eight hours without any adjustment being needed to e variable transformer. The temperatures of the graphite ecimen measured with the optical pyrometer were lower an that of the internal surface of the carbon tube by 20 1000° C and 40 at 1800° C. The amount of gas leaking om the furnace was small, no fluorescence being visible in e discharge tube for vacuum testing after several minutes. he graphite specimen rod was prepared by extruding the aphite powder mixed with a minimum quantity of coal tar rough a glass capillary.

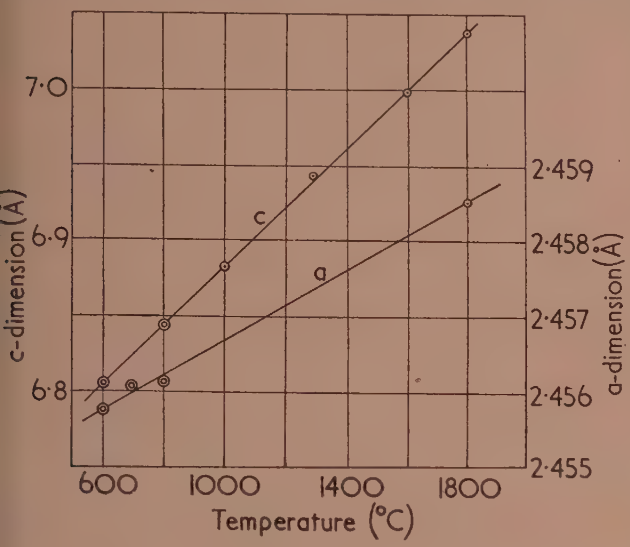


Fig. 3. The thermal expansion of graphite

The diffraction patterns of the Ceylon graphite at 1800° C e shown in Fig. 2. The high-temperature pattern was posed first and then the comparison pattern at room temerature, in order to avoid any permanent change in the ecimen that might have occurred at the high temperature. he upper pair of patterns was obtained with unfiltered copper diation. The shift of the 0004 line is largest, corresponding to the large thermal expansion in the direction normal to the basal plane of the graphite. The $10\bar{1}1$, $10\bar{1}2$ and $10\bar{1}3$ lines have shifted to a marked extent to the left. In contrast with these lines, the shift of $10\bar{1}0$ and $11\bar{2}0$ lines is very small, corresponding to the small thermal expansion in the basal plane; however, a slight shift of $11\bar{2}0$ line may be noticeable. To clarify this point, a pattern obtained with chromium radiation is shown in the lower part in Fig. 2, where the $K\alpha_1$ and $K\alpha_2$ doublet is clearly resolved and, as will be seen, the amount of the line shift at 1800° C is about one-half of the doublet separation. The shifted angles were determined by interpolation from the neighbouring lines of known glancing angles computed from Nelson and Riley's values of *a*- and *c*-dimensions, namely 2·45626 Å and 6·6943 Å respectively at 14·6° C. The variation of the *a*- and *c*-dimensions with temperature is shown in Fig. 3, where double circled points indicate Nelson and Riley's values. The points obtained by the author are on the straight lines extended from their curves. The coefficients of the thermal expansion between 1000 and 1800° C, as well as the values obtained by other workers, are given in the following table. In spite of large probable errors involved in the thermal expansion coefficient of *a*-dimension obtained by Nelson and Riley, as will be understood from Fig. 3, the value is in close agreement with the present one.

The coefficients of thermal expansion of graphite

	c-dimension	*a-dimension*
Ceylon graphite	$28{\cdot}09 \times 10^{-6}$ (1000–1800° C)	$0{\cdot}95 \times 10^{-6}$ (1000–1800° C)
Ceylon graphite(3)	$27{\cdot}00 \times 10^{-6}$ (14·6–800° C)	$0{\cdot}9 \times 10^{-6}$ (600–800° C)
Graphitized graphite(5)	$28{\cdot}6 \times 10^{-6}$ (−196–1118° C)	—

REFERENCES

(1) Basinski, Z. S., Pearson, W. B., and Christian, J. W. *J. Sci. Instrum.*, **29** p. 154 (1952).
(2) Chiotti, P. *Rev. Sci. Instrum.*, **25**, p. 683 (1954).
(3) Nelson, J. B., and Riley, D. P. *Proc. Phys. Soc.* [*London*], **57**, p. 477 (1945).
(4) Riley, D. P. *Proc. Phys. Soc.* [*London*], **57**, p. 486 (1945).
(5) Walker, P. L., Jr., McKinstry, H. A., and Wright, C. C. *Industr. Engng Chem.*, **45**, p. 1711 (1953).

Laboratory and workshop notes

A rapid and simple method for obtaining permanent records from cathode-ray oscilloscopes

By H. D. Rathgeber, Dr.Ing., F.Inst.P., The F.B.S. Falkiner Nuclear Research Laboratory University of Sydney, Australia

[*Note first received* 9 *November, and in final form* 7 *December*, 1954]

The author has been using for several years a simple and rapid method for obtaining permanent records from cathode-ray oscilloscopes which does not appear to have been mentioned or used elsewhere.

A piece of transparent plastic tape, which is obtainable in widths of up to several inches, is stuck on the face of the cathode-ray tube and the curve is traced with a ball-point pen. If care has been taken to keep the plastic tape clean, and after some experience, a very fine, clear and accurate record of the curve can be obtained quickly. The visible record provides an immediate check on the accuracy of the tracing. Any detail which is visible can be reproduced and the size of the record is only limited by that of the screen. In cases where accuracy is important, for instance in testing the response of networks to square pulses, it is advisable to eliminate parallax errors by providing a sight.

Ball-point pens of different colours allow the recording of several curves on the same piece of tape. Stripping the tape from the tube and sticking it on paper, preferably graph paper, gives a permanent record.

A similar method,* requiring additional equipment, has been described. It has the further disadvantage that it does not show the record as it is being traced.

---

* Walton, E. T. S. *J. Sci. Instrum.*, **22**, p. 54 (1954).

Holes of small diameter in stainless steel

By H. G. Jerrard, B.Sc., A.Inst.P., Physics Department, University of Southampton

[*Note received* 7 *January*, 1955]

Recently it was necessary to make circular holes of diameters 0·01 in. and less in stainless steel disks of varying thicknesses up to 0·375 in. These holes were to be observed under a microscope and it was essential that the contour should be accurately circular. Such small holes proved impossible to drill by normal methods. A solution was reached by using hypodermic needle tubing and stainless steel capillary tubing (obtainable from Accles and Pollock Ltd.). Hypodermic tubing can be obtained with different external diameters and with uniform bores of diameter from 0·007 in. upwards: capillary tubing can be purchased with internal diameters in the range 0·004 to 0·016 in. and external diameters from 0·06 to 0·4 in. In both types the tolerance on the internal diameter is ±0·001 in. The contours are circular to a remarkably high degree, particularly so for blood transfusion tubes which also have a specially finished smooth bore.

Short lengths of tubing with nominal size of bore equal, or near, to that required were examined until the correct size was found; this was not a lengthy process. Where tubes of different external diameter and the same internal diameter were available, the largest was taken. A length, dependent on the thickness of the disk, was cut and fitted by slight pressure into the stainless steel disk through which a hole of diameter equal to the external diameter of the tubing had been made. It was possible to drill this hole in the normal way, since it was of large size relative to the size of the hol required and the shape of the contour was not importan The tubing was an interference fit in the hole, but it wa pressed in very carefully so as not to cause distortion. Bot faces of the disk were then turned up in the lathe. In orde to clean up the edge of the hole, the disk was held in a chuc and a sharply pointed sewing needle, mounted in the lath tailstock, brought up so that its point just entered the hol with its sides touching lightly on the edge. The disk wa rotated at moderate speed for a few seconds. The disk wa reversed and the procedure repeated. The holes were cleare by passing a thin piece of soft wire through them while hel under benzene. Excellent contours were obtained even whe the hole was magnified some forty times.

Thanks are due to Professor A. M. Taylor in whose depar ment research on flow birefringence, of which this forms part, is continuing.

A low-temperature microscope stage for metal specimens

By D. Hull, B.Sc., and R. D. Garwood, M.Sc., Metallurgy Department, University College of South Wales and Monmouthshire

[*Note received* 14 *January*, 1955]

The microscopical examination of metal surfaces at temperatures below 0° C is not a new technique. A method wa described by Rosenhain and Murphy(1) in 1927 for th casting, polishing, etching and microscopical examination c low melting point amalgams. The growing interest in th mechanism and kinetics of phase changes has led to furthe development of both high- and low-temperature microscop stages.(2,3,4) These are particularly useful in the study c martensitic transformations which primarily occur durin continuous cooling or heating. Large regions of the paren lattice within narrow lamellae undergo homogeneous distortions of the shear type, producing relief effects on th flat, polished surface of the specimen. A number of meta and alloys undergo changes of this type at sub-zero temperatures, e.g. metallic lithium, alloys of lithium and magnesium 60 : 40 brass and austenitic nickel steels.

At low temperatures the main difficulty is to prevent th deposition of a layer of frost on the surface of the specime and the objective. In the stage designed by Greninger an Mooradian(4) the specimen is held in an evacuated chamb and viewed through a glass window. The sample is fixed i the end of a copper rod which projects through a seal into th cooling medium. The apparatus is adequate for examinati at low magnifications, but when the observation of fine detai is important, the reduced working distance of the high resolving power objectives necessitates a very thin gla window, almost in contact with the polished surface of th specimen. At the lowest temperatures this leads to th condensation of ice crystals on the outside of the windov thus blurring the field.

This difficulty is overcome by a simple modification Greninger and Mooradian's stage. The apparatus is illu trated in Fig. 1. A specimen of rectangular section is fixe in a slot cut in the end of the copper cooling rod and he firmly in position by means of a polished copper wedge (s Fig. 2). The rod projects through the cylindrical case ebonite and a gas-tight seal is obtained with a lead gaske The space between the objective and the specimen is enclose within a flexible rubber envelope through which dry air gas is passed. The enclosure is easily obtained by sectioni an ordinary air balloon. The inflation tube will grip tight an objective with a long $\frac{1}{2}$ in. barrel, e.g. the 4 mm type Cooke, Troughton and Simms Ltd., whilst the sectioned d can be tied around the grooved ebonite case of the stage ith a strong rubber band. Perfect seals are not required,

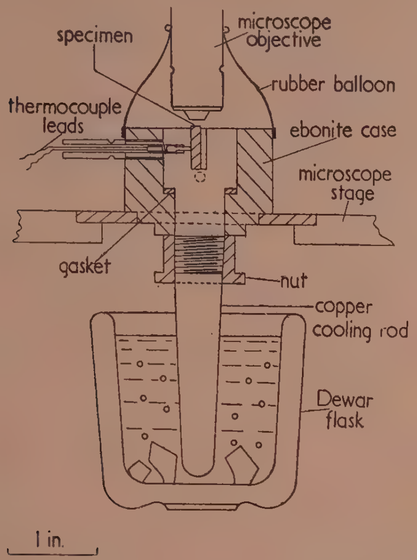


Fig. 1. Details of the low-temperature stage

nce a slight positive gas pressure is maintained within the closed space. The dry gas should be flushed through the pparatus for about 30 min before cooling and it is advisable store the balloon envelope in a desiccator between use. he ebonite case is clamped to the microscope stage which hould be of the mechanically traversing type. Considerable and fro motion is allowed by the elasticity of the balloon velope. The cooling rod projects through a hole in the

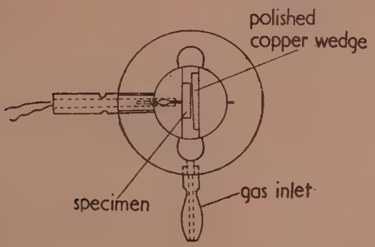


Fig. 2. Plan of copper cooling rod

age into a Dewar flask containing the cooling medium. he temperature of the specimen is measured by a fine ermocouple held in a plastic sleeve against the specimen a small spring. The objective should only be lowered to e focus position whilst observations are being made.

REFERENCES

) ROSENHAIN, W., and MURPHY, A. J. *Proc. Roy. Soc. A*, **113**, p. 1 (1927).

) GLOVER, S. G. *J. Inst. Metals., Bull.*, **2**, p. 181 (1954).

) CECH, R. E. *Rev. Sci. Instrum.*, **21**, p. 747 (1950).

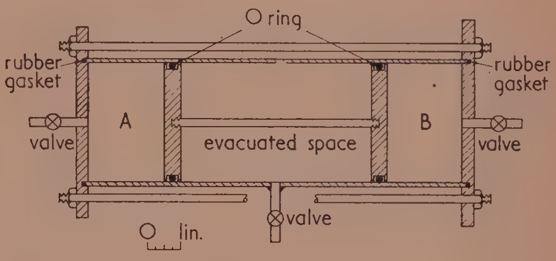
) GRENINGER, A. B., and MOORADIAN, V. G. *Trans Amer. Inst. Min. Met. Engrs*, **128**, p. 337 (1938).

A constant pressure gas storage vessel

By G. W. GREEN,* Atomic Energy Research Establishment, Harwell, Berks.

[*Note first received* 9 *November, and in final form* 20 *December,* 1954]

The gas storage vessel to be described was designed to supply the ion source of a Van de Graff generator through a suitable control valve. As only about one litre of the gas to be used was available, it was necessary to adopt a method which would enable the vessel to be completely emptied, so as to obtain the maximum running time with one filling; and a reasonably constant delivery pressure was desirable to obtain the required flow of gas without the need of a control valve with a very wide range. The system devised meets these requirements and has an incidental feature in that the higher the ratio of the output to the input pressure the more constant is the delivery pressure.



A constant pressure gas storage vessel

The general arrangement is shown in the figure. The vessel consists of a hollow mild-steel cylinder with polished bore containing two pistons sealed by O-rings. These pistons are rigidly connected together by a rod, but are otherwise free to move axially as a unit. The dimensions are chosen so that the space between the pistons always communicates with a port mid-way along the length of the cylinder, irrespective of the piston assembly position. There is also a port at each end, each of which is provided with a valve.

The gas to be used is pumped into one end A of the cylinder, at say $\frac{1}{10}$ of the required delivery pressure, with the piston assembly moved to give maximum volume. The valve is then closed. Compressed air, or other convenient gas at a pressure equal to the required delivery pressure, is then pumped into the other end B, thus moving the piston assembly which in turn compresses the gas in A to the same pressure. Since the subsequent movement of the piston assembly, as the gas in A is used, is small, the volume change and therefore the pressure change in B is small; also, since the pressures at each side of the piston assembly are approximately equal, the pressure change at the outlet is small also. The space between the pistons is evacuated and sealed, or continuously pumped, so that the very small leakage across the piston seals does not cause the gases to mix. For many applications a single piston would suffice. The use of tie rods to attach the ends avoids the use of flanges with their subsequent welding or brazing.

---

* Now at Radar Research Establishment, Malvern, Worcs.

The British Instrument Industries' Exhibition, 1955

A PREVIEW

The third British Instrument Industries' Exhibition will be held at Earls Court, London, from 28 June to 9 Jul 1955. It will show the latest products of manufacturers of scientific and electrical instruments, industrial meter automatic controls, drawing office equipment, scientific glassware, and similar equipment. This exhibition offe the industrialist the opportunity to examine the latest methods and apparatus which are now at his disposa experienced technicians will be available throughout the exhibition for consultation.

Admission to the exhibition will be by invitation-tickets to be distributed by the exhibiting firms or upon payme of 2*s.* 6*d.* at the door.

The exhibition is sponsored and actively supported by the following Associations: The British Electrical an Allied Manufacturers' Association, The British Industrial Measuring and Control Apparatus Manufacturers' Assc ciation, The British Lampblown Scientific Glassware Manufacturers' Association, The Drawing Office Material Manu facturers' and Dealers' Association and The Scientific Instrument Manufacturers' Association of Gt. Britain Lt

From the diverse material submitted to us by exhibiting firms we have somewhat arbitrarily selected a few item to demonstrate, particularly to our readers in industry, that a visit to this exhibition will be worthwhile.

Airflow Developments, The White House, New Road, Booker, High Wycombe, Buckinghamshire.

Portable airflow test set. The principal item that will be shown is a complete portable equipment for testing fan systems. The three manometers (Fig. 1) are an inclined one for range 0 to 2·5 in. w.g. giving a 10 in. movement per inch w.g.; another inclined one for the range −0·5 to +6 in. w.g. giving a movement of 4·167 in. per in. w.g.; and for the range 0–27 in. w.g. a swinging arm, vertical type giving direct readings on a slightly contracted scale which compensates for the fall of liquid level in the tank with the rise in the tube. All three manometers are of the single-limb type comprising in each case a borosilicate precision bore glass tube mounted along its entire operating length in a grooved tubular support and connected to a metal reservoir tank at the rear of tl panel. The grooved tubular support is subject to a ver accurate straightening process in a specially designed machi before final assembly and, for the inclined gauges, is provide with an adjustment at its lower end to allow for calibratic against a laboratory standard manometer before being final locked in position.

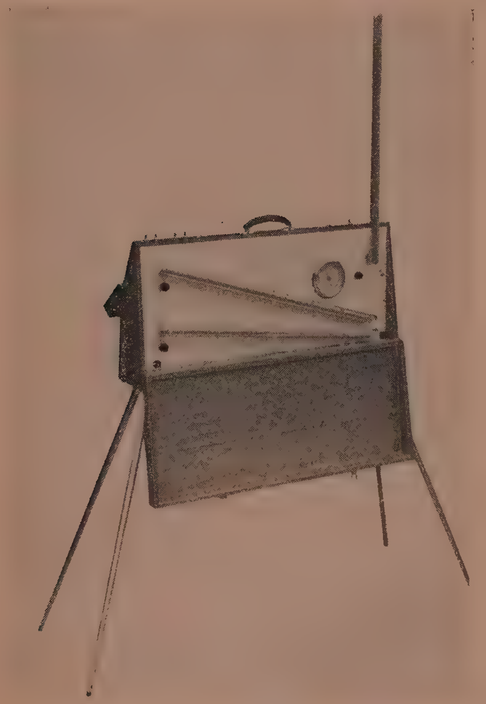


Fig. 1. Portable airflow test set

The set includes an adjustable aneroid barometer with range of 26–32 in. but other ranges can be provided. Th Pitot static tube is 31¼ in. long and is suitable for use in gase up to 690° C. It is of the latest N.P.L. pattern incorporatin the modified ellipsoidal nose. A range of these in stainle steel will be exhibited.

Aldis Brothers Ltd., Priory Works, Sarehole Road, Hall Gree Birmingham, 28

Long range signalling lamp. This new signalling lam although less than a pound heavier than its well known pre decessor signals with over five times the light output. Th signals are made by means of a tubular shutter which com pletely obscures the light from the continuously burnin 60 W, 12 V lamp. The Aldis Secret Device is incorporate which by reduction of the strength of the beam enables th lamp to be used for night signalling or at close quarter There is a built-in telescopic sight of magnification approx mately × 2.

Reflecting gun sight. The Nife reflecting sight (type SRS–5 which is being manufactured under licence from Swede has a wide field of view and employs both eyes. It is intende to meet the requirements of modern anti-tank and ant aircraft defence.

Baird and Tatlock (London) Ltd., Freshwater Road, Chadwe Heath, Essex

Centrifuge. The "wide range" centrifuge has been designe to carry out a comprehensive range of work using bucke capacities ranging from 5 to 540 ml with a maximum loa capacity of 2160 ml. The speed is continuously variable u to 5000 rev/min by the use of a variable autotransformer.

Oil testing centrifuge. The Astip oil testing centrifuge com plies with the I.P. and A.S.T.M. requirements, where centrifuge is required with a bucket capacity of not more tha 100 ml. All the tests specified can be carried out with th use of various interchangeable accessories. A single centrifuge head only is necessary so that changes of this part are not required.

Precision balances. A range of four precision balances will be exhibited. (*a*) An undamped analytical balance having a capacity of 200 g and sensitivity of 0·1 mg/division. The beam is notched and engraved for a 5 mg rider which is easily operated from a control located outside the case. (*b*) An air-damped balance having a capacity of 200 g and employing an optically projected scale providing readings from 0 to ±10 mg. The sensitivity is 0·1 mg/division. (*c*) An air-damped balance as above but provided with a hand-operated weight mechanism fitted externally to the case which eliminates the use of all loose fractional weights. (*d*) An air-damped balance as above but provided with a hand-operated weight mechanism which eliminates the use of all loose weights up to the capacity of the balance, i.e. 200 g.

Magnetic, mercury-cathode, electrolytic analysis apparatus. A method has been developed by the British Iron and Steel Research Association for the mercury-cathode electrolysis of steel solutions. The specified conditions are applicable over a wide range of alloy compositions and tests have shown that the residual electrolyte quantitatively contains, and can be used for the determination of elements such as aluminium, titanium, vanadium and zerconium. The conditions are designed to permit the optimum removal rate of cathodically deposited elements, for example, iron, chromium, nickel, on a large weight basis, thus providing a solution suitable for the determination of residual trace constituents such as aluminium or titanium of even less than 0·01%. The apparatus to be shown has been designed with the co-operation of the association.

Beta and gamma radiation monitor. The monitor to be exhibited is intended for the detection and counting of beta and gamma rays emitted from a radioactive source such as ^{14}C. It is simple in design and is primarily intended for demonstration purposes in educational establishments. A microammeter is capable of registering counts up to approximately 40 particles per second. A flashing trigger tube is visible through a window which can be used for observing low count rates.

Other exhibits. Among other exhibits will be an improved Karl Fischer apparatus, an apparatus for the determination of the low temperature flexibility of vinyl elastomers, a penetrometer for bitumen grease tests and a wide range of laboratory apparatus.

R. and J. Beck Ltd., 69 Mortimer Street, London, W.1

Microscope employing the crushing technique. The initial research on the crushing technique has been carried out by Dr. R. G. H. B. Boddy, who has shown that most opaque microscopic material can be rendered transparent if it is crushed until nearly flat. For example, mixtures of small opaque mineral particles can be differentiated and assessed after crushing, each material having a characteristic appearance, which is not apparent before the pressure is applied. Since the behaviour of the material during crushing is also a useful guide to its nature, observations must be conducted whilst the crushing pressure is being applied. Although originally developed for work on the identification of mineral mixtures, the usefulness of the technique has now been extended to include biological material and fibres. The microscope developed for this work will be shown.

Microscopic and optical apparatus. The firm's wide range of microscopic and optical apparatus will also be on show.

Belling and Lee Ltd., Great Cambridge Road, Enfield, Middlesex

Fuse-links. A range of fuse-links to be shown will include the general purpose instrument fuse-link L.1055, now manufactured by an entirely new technique which bonds caps, glass and filament into one unit. The Airfuse fuse-link for aircraft is intended as a direct replacement for the American current limiter.

A new range of six fuseholders for inter-service use has been developed, in addition to the existing types of sealed and neon indicating versions, including an Admiralty sealed fuseholder.

Screened plugs and sockets. Screened plugs and sockets with 4, 6 or 12-way assemblies which are interchangeable are to be shown.

Printed circuit connectors. Printed circuit connectors (Fig. 2) and improved Unitors will be exhibited.

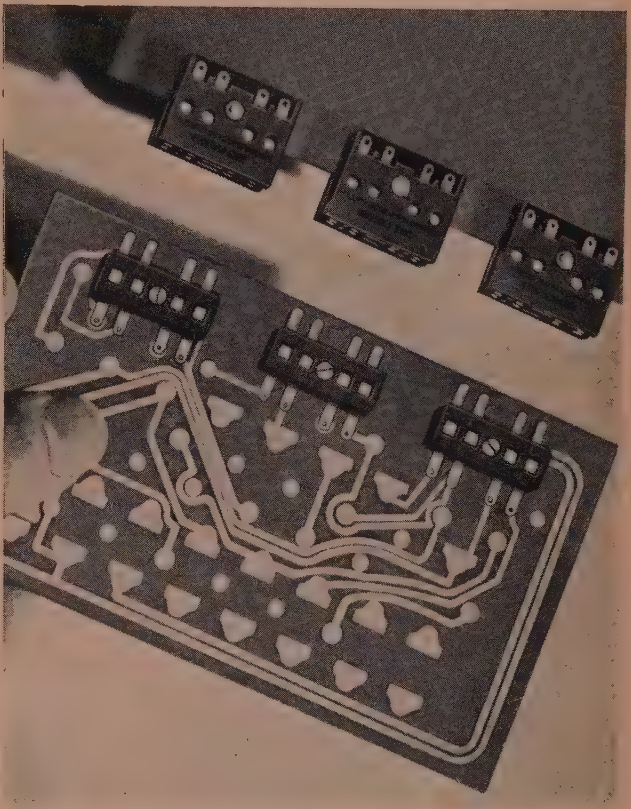


Fig. 2. Printed circuit connectors

Other exhibits. These will include: 3 and 4 mm resilient sockets with square-faced nylon moulding, interference filters effective at television or broadcast frequencies, aerial equipment, attenuators, chokes (r.f.), cut-outs, filters (h.f.), fuseholders, inductors, interference suppressors, plugs and sockets, seals (hermetic), switches (thermal delay), terminals, valveholders, valve retainers.

Bellingham and Stanley, Ltd., 71 Hornsey Rise, London, N.19

Optical instruments. This firm's range of instruments includes spectrographs and spectrometers, refractometers, colorimeters and polarimeters, examples of which will be exhibited. The following may be of special interest.

Precision refractometer. The instrument to be shown is stated to measure to an accuracy of 0·00002 refractive index. It is of the Abbe type but is only intended for use with a monochromatic light source, principally sodium light, but if required the prism can be arranged to deal with other sources such as the principal spectral lines of mercury, hydrogen, etc. The divided arc of the instrument reads directly in degrees while a micrometer screw and divided drums read directly to 10″. Tables are provided for use with sodium light to convert arc readings to refractive index. This instrument isvery rapid in action and, provided the prism has been calibrated for two or more spectral lines, dispersion measurements can be determined to the same order of accuracy as with sodium light.

Polarimeter. Several improvements have been made in the design of this firm's Model D polarimeter and in the divided circle which is on glass; degrees are sub-divided by the micrometer screw and divided drum head. This reads to 0·02°. The circle carries a sugar scale when required in addition to the circular dividing. The stand of the polarimeter is in one piece and the trough which carries the observation tube is inclined at a convenient angle for observation. The trough will carry observation tubes up to a length of 22 cm and also the usual water-jacketed tubes.

The British Rototherm Co. Ltd., Merton Abbey, London, S.W.19

Process recorder. The Talligraph Recorder is operated by a mercury-in-steel-system and a gravity-operated, precision, gear-train mechanism which obviates the need for an electric or spring-wound clock. The instrument produces a graphic record of each process-cycle on a separate card on which vertical temperature lines can be read at a glance; these are useful features in sterilizing processes in operating theatres. One- and two-pen models are available for simultaneously recording temperature, pressure and vacuum.

Temperature gauges and recorders. Examples of the firm's bimetallic, mercury-in-steel and vapour pressure temperature gauges and recorders will be exhibited.

Crompton Parkinson Ltd., Crompton House, Aldwych, London, W.C.2

Electrical indicating instruments. A wide selection of ammeters, voltmeters, frequency indicators, power factor indicators and synchroscopes will be shown, several of which have been recently introduced. The Admiralty pattern shockproof instruments, including the new power factor indicators and synchroscopes, have been built to withstand exceptionally arduous service conditions. The hermetically sealed, circular scale instruments have been built to withstand a temperature range of 40 to 158° F under conditions of 95% humidity, to sustain without leakage an internal pressure differential of 10 lb/in.^{2} and they are shock resisting up to 50 g.

Other instrument exhibits include switchboard mounting 4 in. and 6 in. dial types and the six latest types of long-test equipment.

A. C. Cossor Ltd., Cossor House, Highbury Grove, London, N.5

Cathode-ray oscillographs and auxiliary equipment. Three single-beam and three double-beam cathode-ray oscillographs will be exhibited, some being new models with special features. Two models of a 35 mm camera and a nine-speed camera for use with these oscillographs will also be shown.

F. M. receiver alinement generator. The Model 1324 F.M. receiver alinement generator to be shown is designed for use by service engineers to follow essential alinement procedures of F.M. broadcast receivers.

Costain-John Brown Ltd., 73 South Audley Street, Londo W.1

Instrumentation for process control. The exhibits will ill strate the various services in the field of instrumentation ar automatic process control provided by this firm. An instr ment cubicle made up from standardized panel sections w be exhibited. This will contain instruments from most of t leading instrument manufacturers and will be fully piped ar wired to demonstrate various piping and wiring technique Amongst other exhibits will be an example of graphic pan work.

Visitors to this stand will be invited to inspect the Instr mentation Division's design office and works which is a fe minutes walk from the exhibition.

Crosby Valve and Engineering Co. Ltd., Crosby Work Ealing Road, Wembley

Pressure and level controllers. A working model of t Mason–Neilan displacement type, level controller and val will be shown together with ancillary equipment. The ne series 12800 instrument incorporates a number of improv ments.

Valves and regulators. A comprehensive range of valv and regulators will also be exhibited.

Dawe Instruments Ltd., 99 Uxbridge Road, London, W.5

Noise generator. This device provides a wideband source "white" noise covering the audio and video frequency band The circuit consists of a thyratron valve noise source followe by a wideband amplifier.

Thickness gauge. The Visigauge measures the thickne of electrically conducting materials from one side, giving visual indication of the thickness on a calibrated cathode-ra tube screen. It is primarily intended for measurements o smooth flat surfaces, but good results have been obtained o convex surfaces down to 4 in. diameter and on pitted surfac which are electrically clean. The Visigauge uses a quar crystal transducer to set up ultrasonic vibrations in the thick ness direction of the material under test. The quartz cryst is excited by an electronic oscillator, the frequency bein represented by distance along the time base trace of t cathode-ray tube screen. As the frequency passes throug the fundamental or a harmonic resonance value of the materi under test, increased power is drawn from the oscillator. Th power change is amplified and used to provide a vertical p on the calibrated time base trace. Five crystals cover t range 0·015 in. to 0·300 in. for steel and a directly calibrate scale is provided for each of the five ranges. Calibration the equipment for use on other materials is easily achieved b using test blocks of known thickness and measurements u to about 4 in. can be calculated from harmonic resonanc indications.

Sound level indicator. This miniature instrument com prises a crystal microphone, a switched attenuator calibrate in 10 dB steps, an amplifier with three weighting networks, 30 dB attenuator and an indicating meter. Access to th batteries is readily obtained by removing one nut and the bas cover plate. To read battery voltages on the internal mete a "battery check" facility is employed.

The instrument can be held in the hand and provides means of comparing the intensity of similar sounds and meaking a preliminary investigation of noise sources. Soun pressures may be measured between 30 dB and 135 dB abov the reference level of 0·0002 dyn/cm^2.

Electrical hygrometer. The instrument measures th ariation in capacitance with change in atmospheric humidity f a moisture permeable electrode. An aluminium rod is nodized along part of its length to form a dielectric or luminium oxide. It is then coated with an electrically onducting layer which forms the second electrode of the apacitor. Several electrode assemblies are under developent with various forms of mechanical protection.

The instrument will cover the range 20–85% r.h. and the ndication is virtually independent of temperature. Both ains- and battery-operated models are being developed.

oran Instrument Co. Ltd., Stroud, Gloucestershire

niversal bridge. The bridge uses a normal Wheatstone ridge circuit supplied with d.c. from the main rectifier system nd a galvanometer is used as the null detector for resistance easurements. The energizing voltage for the measurement f inductance and capacitance is provided by a self-contained scillator having a nominal frequency of 1000 c/s and a.c. ains driven. The circuit used for inductance measurements that of the Hay's bridge and for capacitance a modified de auty Bridge.

Dispersion meter. The dispersion meter is designed to rovide a direct measurement of the dielectric dispersion f the insulation of electrical equipment or of samples of nsulating materials. Dielectric dispersion is the variation of ielectric constant with the frequency of sine waves or with he duration of square waves. It is particularly suitable as a est for dryness. A scale reads directly in leakage time-onstant. This measurement is similar in nature to d.c. nsulation resistance measurements but it has the advantage f yielding a figure of merit which, like dispersion, is a roperty of the material and is independent of the shape or ize of the specimen.

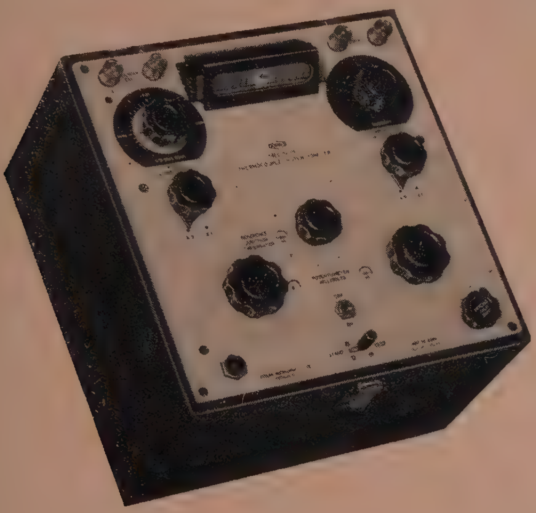


Fig. 3. Precision thermocouple potentiometer

Thermocouple potentiometer. The instrument to be exibited has ranges of 20 and 100 mV and is direct reading to 0 and 50 μV respectively; each of these values being repreented by one division on the slide wire dial. To enable the nstrument to be employed for the checking of thermoelectric ndicators and recorders, an additional unit is provided, hich gives an adjustable e.m.f. from 0–100 mV which is pplied to the instrument under test.

Precision thermocouple potentiometer. This instrument Fig. 3) (No. E.4227) has been designed for the precise checking of thermocouple pyrometers and can also be used for general measurements with both base and rare metal thermocouples. Two ranges are provided of 18 and 90 mV, reading directly to 0·01 and 0·05 mV respectively. A reference junction compensator is provided with ranges of 1 and 5 mV, either compensator range being available for use with either of the main ranges of the potentiometer.

The reference junction compensator consists of a slide wire and this, as well as the main potentiometer slide wire, is subdivided into 100 divisions, one division in each case representing 0·01 and 0·05 mV according to the range used. Range switches are provided for both the potentiometer and reference junction compensator.

Conductivity bridge. This instrument has been designed to enable measurements of conductivity to be made with simplicity of operation and to give direct readings with sufficient accuracy for general laboratory work. A range of 0·1 to 100 000 Ω or 0·00001 to 10 mhos is provided to enable the instrument to be used for conductometric titrations in alcoholic of other non-aqueous solutions as well as certain precipitation titrations.

E.M.I. Electronics Ltd., Hayes, Middlesex

Electronic instruments. This firm will be showing representative examples of their wide range of electronic instruments for scientific and industrial applications; among those recently developed are the following.

Oscilloscopes. Type WM.1 is a compact, general-purpose oscilloscope with facilities for instantaneous voltage measurement. Type WM.3B is a lightweight precision instrument, with facilities for instantaneous measurement of time and voltage. Type WM.5 is a new wide-range console equipment with facilities for instantaneous time and voltage measurement, designed for simple addition of sub-units to increase versatility and performance range.

Dynamic balancing equipment. Bench-type balancers catering for workpieces weighing up to 15 lb and 5 lb respectively, and a console balancer, available in three versions, catering for workpieces in the weight range 4 oz–150 lb. Both types employ transducers as the detecting elements.

Sub-miniature relay. The hermetically sealed, high-speed relay with single-pole changeover and balanced armature, capable of up to 100 operations per second. The operating temperature range is −40 to 100° C and relays are available with coils for 6, 12 and 24 V operation. The dimension are 0·64 × 0·64 × 0·74 in.

Stroboscope. High-power stroboscope (type 3) for observation and measurement of speed of rotating and reciprocating mechanism. It is direct reading over the range 200 – 6000 rev/min. The useful range extends beyond 48 000 rev/min.

Endecotts (Filters) Ltd., 251 Kingston Road, Merton Park, London, S.W.19

Test sieves. In addition to the usual range of test sieves a new portable field sieve will be shown, Fig. 4 (overleaf). This is supplied with interchangeable bottoms of any specified mesh, is 12 in. square and can be used with or without the rocker receiving pan. The screens are held in place by quick-action clamps and can be quickly changed from one mesh to the other, all the screens can be clamped into the frame for carrying when not in use.

There will also be a demonstration of the rapid segregation of particles in transparent rimmed sieves on the Endrock No. 1 Sieve Vibrator; visitors will see the movement of the particles over the surface and through the wirecloth.

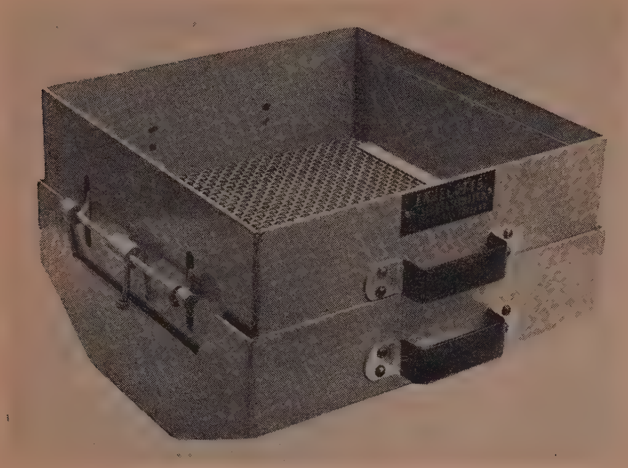


Fig. 4. Portable field sieve

Evans Electroselenium Ltd., Potter Street, Harlow, Essex

Blood cell counter. In the prototype model to be shown the diluted blood sample is introduced into the instrument and by means of a water system the blood cells are drawn out into a single line, when they enter the field of view of the optical system which has dark field illumination. As each cell passes the field of view it appears as a brightly illuminated image. Each image falls on a photo-multiplier photocell which operates a fully stabilized electronic counter, counting up to 20 000 cells per second, the mean rate of count being of the order of 200 per second.

Exposure controller. This instrument, designed to provide constant conditions of photographic exposure, has a hermetically sealed measuring head, containing an emission type photocell, which is mounted at the edge of the copy frame. The current passed by the photocell controls a simple electronic circuit which, after a preset exposure period, operates a relay which may be connected, externally, to operate the camera shutter.

Light integrator. The principle of operation of the light integrator which will be shown is that light from the receiving surface falls on an emission type photocell, which operates a cold-cathode type discharge tube at intervals dependent upon illumination received. Each discharge is counted on a four figured electromagnetic counter, the rate of count being proportional to the illumination.

Hydrogen sulphide meter. In this device the stain made on a lead acetate impregnated paper is measured photoelectrically. The reading is taken on a micrometer calibrated in two ranges 0 – 0·11 and 0·11 – 0·27 parts per million of hydrogen sulphide.

Daylight factor meter. The daylight factor meter to be shown consists of a suitably mounted EEL barrier layer photocell with a microammeter as the indicating instrument calibrated to read up to 5% daylight factor.

Evershed and Vignoles Ltd., Acton Lane Works, Chiswick, London, W.4

Process control instruments. A full range of equipment for the measurement and control of temperature, flow and pressure (of air, gas, steam and liquids), and liquid levels will be shown. A control desk which incorporates a novel form of instrument presentation known as the "In Line Scanner" (Fig. 5) consists of shadow type indicators arranged close together so that the pointer shadows form a continuous lir Each indicator is provided with a centre zero moveme through which passes the measured value and desired val currents in opposition. If the two currents are equal, t shadow pointer takes up a position in the centre of the sca With a number of indicators so mounted, it is possible show a continuous line from which the stability of the pla may be seen at a glance.

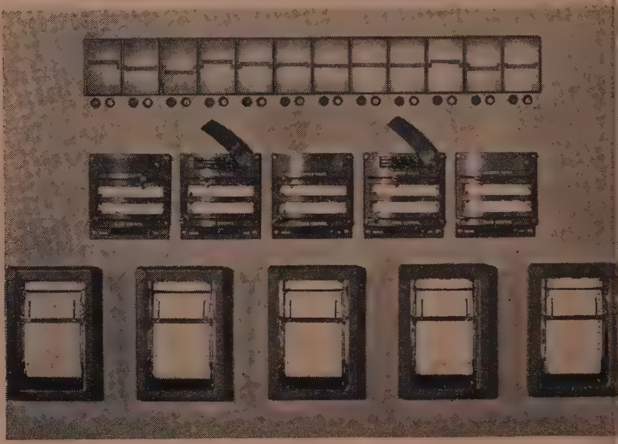


Fig. 5. Graphic panel with "In Line Scanner"

Special instruments for combustion control and measur ment are also on show. These include electro-pneumati electro-hydraulic and all-electric valve positioners—for ai fuel ratio control; an electronic ratio computer for thr element boiler control, and a master pressure transmitt also for boiler control.

Instruments for temperature measurement. Other instr ments to be shown are a radiation roof pyrometer, a electronic thermocouple repeater, a d.c. amplifier for use wi thermocouple measurement of molten-metal temperatur and a B.t.u. meter for high-pressure, hot-water systems.

Ferranti Ltd., Hollinwood, Lancashire

Among the variety of electrical and other instruments ar computers to be shown will be the undermentioned.

Viscometers. A portable viscometer giving instantaneo readings over a wide range and the Ferranti–Shirley cone ar plate viscometer giving a continuously variable rate of shea

Electric motor units. Among the motors to be exhibite will be a precision speed controlled unit for 10 – 3000 rev/m as well as vibration and hysteresis starting synchrono motors.

Computers and auxiliary equipment. The Pegasus con puter is a medium-sized electronic digital computer in t design of which emphasis has been placed on providir facilities which simplify the preparation of a calculatio The main storage is a magnetic drum with a capacity over 4600 "words."

Other exhibits. The auxiliary equipment to be shown w be magnetic storage drums, a high-speed tape reader, ta spooling equipment and a portable tape punch.

Furzehill Laboratories Ltd., 57 Clarendon Road, Watfor Hertfordshire

Oscilloscopes and ancillary equipment. The equipment to exhibited includes the type O.100 direct-coupled, precisic measurement oscilloscope for d.c. to 4 Mc/s, the type C.7

notorized, continuous-film oscilloscope camera and the types .120 a.c. coupled and O.130 d.c. coupled portable, audio requency oscilloscopes.

Inductance bridge. The incremental inductance bridge, ype B.800, provides direct readings of inductance (50 mH 500 H) and Q (3 to 160), with d.c. polarizing current up 1·5 A, if required. It is suitable for use at frequencies rom 25 c/s to 3000 c/s.

Valve voltmeter. The type V.200, wide-band, sensitive, mplifier-type, valve voltmeter to be shown covers the range 0 c/s to 6 Mc/s and is usable up to 15 Mc/s. It measures rom 100 μV to 1000 V r.m.s. in six ranges.

Other instruments. This firm will also exhibit low-requency oscillators, stabilized a.c. and d.c. power supply nits and electronic watchtimers.

. Gallenkamp and Co. Ltd., 17–29 Sun Street, Finsbury quare, London, E.C.2

he wide range of laboratory apparatus to be displayed will nclude electric furnaces, ovens, incubators, stirrers, photo-lectric colorimeters, Kjeldahl nitrogen apparatus, shakers, umidity conditioning ovens, a fraction collector, particle ize analysis apparatus, laboratory glassware and sintered ltration apparatus.

he General Electric Co. Ltd., Magnet House, Kingsway, ondon, W.C.2

emote indication of pressures and displacements. One of the ain features on this stand will be the electromagnetic transucer system developed for the remote indication of pressures nd mechanical displacements. It enables mechanical dislacements of less than 0·001 in. to be measured directly and, vhen used with a suitable pressure responsive element such s a diaphragm, can be adapted for measuring pressures from few inches of water gauge to over 200 lb/in^2. When used vith a Bourdon tube it will measure pressures up to 0000 lb/in^2. The system comprises an electromagnetic neasuring head and a moving coil instrument of the dynamoneter type. Alternatively a recorder-controller can be perated directly off the measuring head where required. No thermionic valves, barretters, rectifiers or magnetic mplifiers are used, and the system is independent of variaons in mains supply. Sectional models on the stand will llustrate the operation of the transducer. A working model vill show how the transducer can be used for measuring head of water in two different ways: by measuring the veight of liquid in a column and by recording the change n the apparent weight of a rod suspended in the liquid.

Other exhibits. Other new equipment will include hernetically sealed instruments which can be seen in operation t high and low temperatures and a range of precision otentiometers. A magnetic sorting bridge, a selection of anel mounting and switchboard instruments, some link esting instruments, an illumination meter, some miniature ayer thickness meters and various portable and sub-standard nstruments will also be shown. Sample powder magnets vill be exhibited alongside a selection of small instruments nd meters in which such magnets are used.

lass Developments Ltd., Sudbourne Road, Brixton Hill, ondon, S.W.2

pecialized glassware. The exhibits will include a fractionang column intended for the separation and analysis of omplex petroleum distillations. This has been designed for se with various types of "dumped" packings and has a vapour dividing still head enabling azeotropes which separate into two phases on condensation to be handled.

Accurate differential gear. A differential gear unit of extreme accuracy, with the minimum of backlash, giving smooth running and low torque will be shown.

James Gordon and Co. Ltd., Dalston Gardens, Stanmore, Middlesex

Process controllers and regulators. The exhibit will consist of a selection of the latest types of regulators, relays, etc., used in connexion with the Hagan system of automatic control for boilers, furnaces, steam pressure reduction, desuperheating, etc., and these will be in operation in order to demonstrate their various uses. There will also be in operation a demonstration of Gordon pneumatic sequential control. Such equipment has various applications including the control of soot blowers. A further item of interest will be the Gordon pneumatic power operators for control valves, stop valves, pen stocks and other purposes. Mono-gas-analysis recorders for carbon monoxide and dioxide, hydrogen and oxygen will also be shown as well as Igema distance, boiler water level indicators.

Graseby Instruments Ltd., Kingston By-Pass Road, Tolworth, Surrey

The following small-size instruments will be exhibited.

Accelerometers. The accelerometers to be shown are liquid-damped precision instruments in which the movement of a spring-supported mass system controls the setting of a potentiometer from which the acceleration is deduced. In the recording instrument a stylus provides a trace on a transparent plastic strip driven by clockwork.

Precision, speed-control, portable centrifuge. This machine was developed for the accurate testing of components not exceeding 12 lb under conditions of acceleration between ¼ and 100 *g*. The maximum speed of the table is 750 rev/min and it can be controlled to ¼%. The speed control is by a hybrid electronic circuit which resembles both Velodyne and Ward-Leonard controls. There is an air supply to the centre of the table and this connexion may also be used for suction.

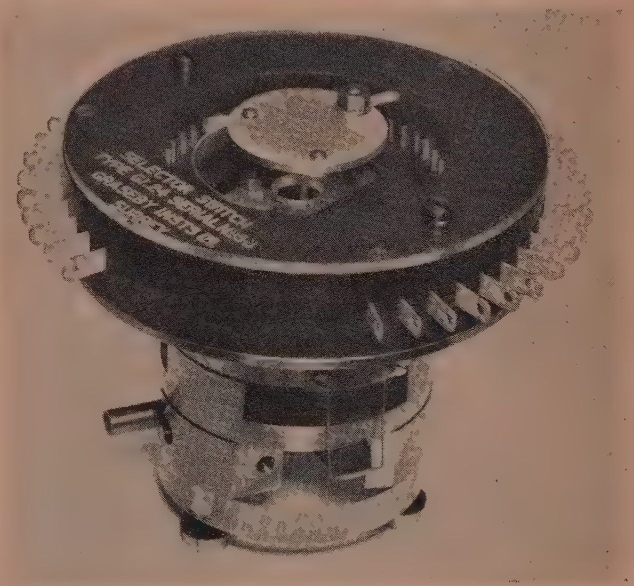


Fig. 6. Selector switch

A number of other useful features are also embodied in this machine.

Solenoid-operated valve. A compact, lightweight, solenoid-operated valve suitable for air pressures up to 2000 lb/in.^{2} will be shown. When connected in the supply circuit balancing pressures exist on both sides of the main valve, the valve being closed by a spring. The action of the solenoid allows one side of the valve to bleed to atmosphere, and the resulting pressure differential opens the main valve which ensures rapid and positive operation. The solenoid is so designed that when once energized the valve is held open by a retaining spring after the removal of the supply voltage.

Gyroscopic apparatus. In the gyro-calibration table to be shown, air and electrically driven gyroscopes can be tested over the range 0–80 rad/s; stability is achieved by means of a drift-compensated Velodyne control system. The Rate-gyro is an electrically driven, liquid-damped gyroscope employing four precision potentiometers, the output of which is proportional to the angular velocity.

Switches. The selector switch to be exhibited is a clockwork-driven, rotary switch unit designed to effect precise intervals of contact duration, Fig. 6. It has a wide application for use as a programme motor where there is a need for a versatile, accurate and reliable switch which is unaffected by severe vibration and acceleration conditions. A range of time-delay switches will also be exhibited. The various types consist of clockwork mechanisms designed to complete one or more electrical circuits at predetermined time intervals. They may be started either by an inertia switch or by a solenoid-operated starting switch.

Hilger and Watts Ltd. (Hilger Division), 98 St. Pancras Way, Camden Road, London, N.W.1

This firm will exhibit examples from its wide range of industrial and laboratory optical instruments including spectrometers, colorimeters, polarimeters, profile projectors, and optical measuring tools. Some of these now have elaborate electronic recordings and reading devices attached to them. Among the new devices the following may be of special interest.

Direct-reading attachment to the medium quartz spectrograph, type E 750. This combination forms a direct-reading spectrometer simpler and less costly than those hitherto available. It is suitable for analyses of up to eleven elements in most non-ferrous alloys. The attachment proper replaces the plateholder of the spectrograph, and it contains slits in the focal plane to isolate the spectral rays required, with individual mirror systems to lead the rays on to individual photomultipliers. Manually controlled temperature compensation is built in. Leads connect the attachment to an electronic console. During analyses, the individual multiplier currents are integrated on their respective condensers. The integration period may be limited at will in one of two ways: (*a*) the clock controls the exposure by elapse of a preset time interval; (*b*) one element is chosen, and the initial voltage on its condenser is arranged to be a reproducible amount below earth potential. When the potential reaches zero by virtue of integration, everything is stopped. Individual switches for each element allow that element to be passed over during the measurement cycle, so as to save further time. At the conclusion of integration the condenser-potentials are measured one by one, at intervals of 5 s. The results are displayed on a meter, and a jack-plug is also provided to allow a pen-recorder to be plugged in.

Fluorimeter. This redesigned instrument is many times more sensitive than earlier models. It is particularly suitable for the analysis of vitamins B_1 and B_2 in flour. The fluor meter attachment is easily removable for converting th instrument into an absorptiometer.

Photoelectric tristimulus colorimeter. This colorimete incorporates a standard light source, an accurately designe photocell and filter combination and galvanometer. It ca be applied to opaque or transparent samples and, by means c special accessories, to liquids in 10 cm tubes and to powde without the intervention of a cover glass. The optical un has an extensible cable connexion and can be removed fro the instrument body and applied, for example, to walls an large sheet material. The instrument gives accurate C.I.E chromaticity and reflectance or transmittance factors for an one of the three standard C.I.E. illuminants *A*, *B* or *C*.

Honeywell-Brown Ltd., 1 Wadsworth Road, Perivale, Greenford, Middlesex

Instruments for process measurement and control. The displa will include many of the firm's regular lines for proces measurement and control and a number of recent developments. A special feature will be a range of miniature instruments.

Flow measurement and control. The exhibits will include pneumatic controller, a ratio controller, a pneumatic receive with electronic integration and an electronic inductanc bridge receiver with integrator. The last-mentioned exhibi is a circular chart instrument which will indicate, record control and integrate flow measurements. The differentia converter and the area type meter will also be exhibited The former is a mercuryless type of manometer operating o the pneumatic force-balance principle and the area type mete varies an orifice area while maintaining the differentia pressure at a fixed value. It was designed for use wit viscous liquids such as hot tar.

Combustion safeguard systems. A display of gas and o flame-safety equipment will include Protectoglo relays whic will stop instantly the flow of fuel to a burner in the event o flame failure. Flame and photocell electrode types will b shown.

Instruments for research and development work. Amon the instruments likely to be of special interest to readers o this *Journal* are a multiple-point precision indicator and one-second pen speed strip chart recorder. The functio plotter which is a strip chart instrument showing the continuous relationship of one function against another will als be of interest.

Hunt and Mitton Ltd., Oozells Street North, Birmingham, 1

Diaphragm-operated, process-control valves. Hitherto th valves manufactured by this firm have not been generall available, but are now offered direct to all users. A rang will be exhibited together with ancillary fittings.

Integra, Leeds and Northrup Ltd., 183 Broad Street, Birmingham, 5

Process instruments and controllers. The wide range o devices to be shown by this firm will include electric thermometers of various types, pH meters, flowmeters and indicator and controllers for many industrial processes.

Isopad Ltd., 30/32 Rosemont Road, London, N.W.3

Electric heating mantles. Whilst the standard constructio (resistance wire interwoven with glass fibre) of these mantle is suitable for temperatures up to 400° C, heating tapes ar now made from quartz cloth allowing working temperature p to 800° C. The exhibits will include heating mantles for ameproof areas similar to that shown (Fig. 7) and automatic ontrols provided for these appliances. The units in flameroof areas operate through intrinsically safe transformers nd relays, which are connected to the main power relay oused outside the flameproof area. A new development the Isopad system of combined resistance and mains equency induction heating allowing loadings up to 2 kW/ft.^{2}

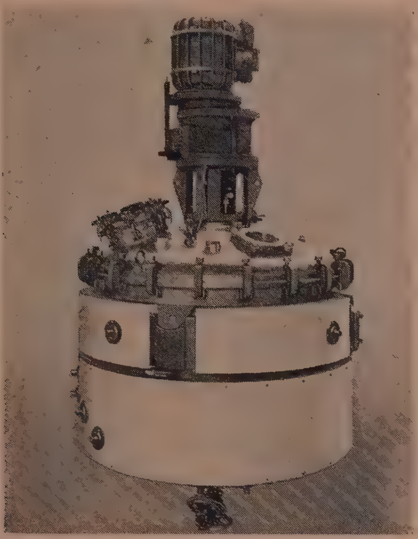


Fig. 7. Electric heating mantle (20 kW) on 680 litre vessel with automatic control, suitable for flameproof areas

ames A. Jobling and Co. Ltd., Wear Glass Works, Sunderland

cientific glassware. This firm will be showing samples from eir complete range of Pyrex laboratory and scientific glassare. There will be many examples of lampworked apparatus cluding a number of the Grip-Seal ground-glass joint ssemblies. One great advance that has been made is the roduction of a range of volumetric flasks and cylinders with terchangeable ground-glass stoppers; each stoppered Pyrex ask and cylinder is now supplied with a stopper ground to e joint sizes recommended in B.S. 1792 and 804.

Educational apparatus. Also on this stand will be the new nge of semi-micro apparatus, specially developed for use in chnical colleges and schools.

elvin and Hughes (Industrial) Ltd., 2 Caxton Street, ondon, S.W.1

uel economy equipment. A working display of an Econoeter with a simulated chimney and including a primary nit fan venturimeter will be shown. This instrument provides the simplest form the information necessary for the mainnance of maximum fuel economy conditions.

Boiler panel. A panel comprising a number of indicating d recording instruments will be exhibited.

Temperature controllers. Another exhibit will be a pedestal nel incorporating an on/off electronic temperature conoller, operating from a thermocouple attached to an electric ht bulb and connected into the new 6 in. strip chart recorder ted with alarm. A new type three-position electronic mperature controller will also be shown.

Shadowless lamps. A display of the newly designed adowless lamps will be given.

George Kent Ltd., Luton, Bedfordshire

Process controllers, recorders and indicators. A number of new industrial measuring and controlling instruments in the firm's interchangeable Commander class, will be shown. There will be a presentation of the Wobbe-index control; instruments and controllers for gas grid control; a new diaphragm-operated gas-pressure controller and oxygen analyser and manometers. Feeder-glass temperature control will be demonstrated as well as the automatic control of glass "metal" level for glass-melting tanks. The automatic control of furnace temperature and combustion for various applications in the steel industry will be exhibited as well as pneumatic computers, bleed units, injector units and power cylinders, for automatic regulation.

Visitors from the water industry may see a working display of the Universal glass-electrode pH recorder, a model of the new Dall tube, a flow transmitter and a wide range of mechanical water meters. An actual trade-effluent control scheme will be displayed in the sewage section, and this includes a flow recorder and pH controller actuating a power cylinder-operated lime dosing trough.

A presentation of the instrumentation of a sulphur recovery plant, and a working installation of "simmering" control as used in the chemical industry will be shown and also rotary-shunt steam meters. For the sugar industry there will be a complete presentation of the instrumentation of a diffusion battery; while the oil industry section will contain a full range of Brodie–Kent meters, a demonstration of an oxygen controller, working in conjunction with a gas-fired heater, and a working model showing the comparison between the Dall tube, the Venturi tube, and orifice fittings as differential producers for flow measurement. Standardization of instrumentation and control for industrial boiler plants is to be a main feature of the steam power industry section, where a set of sectional panels will demonstrate this new trend. Additional features of this industrial division will be a demonstration of a combined turbine and boiler control panel and console, and a display covering the automatic control of the temperature of superheated steam.

Labgear (Cambridge) Ltd., Willow Place, Cambridge

Counting and timing equipment. The display will comprise a range of nucleonic counting equipment and accessories, supplemented by instruments recently developed for use in the field of industrial counting and timing. The apparatus exhibited will include: A fast scaler (type D.4100) in conjunction with a new annular scintillation counter (type D.4105) for high efficiency gamma ray assay. A complete Geiger-Müller counting equipment comprising scalar (type D.4019), power unit (type D.4109/B), pulse amplifier/discriminator (type D.4103) and a simple attachment for paper chromotography. An improved version of the electronic revolution counter incorporating a Dekatron counter (type D.4104) and an automatic timing unit (type D.4102). Three new products, namely, a time period counter (type D.4108), a triple gate ratio counter (type D.4107) and a mechanical add-on register (type D.4109).

Loughborough Glass Co. Ltd., Loughborough, Leicestershire

Industrial bubble-cap column in glass and condensers. A working assembly featuring the bubble-cap column for which advantages over packed columns are claimed will be shown together with the firm's novel coaxial condensers.

Soxhlet solvent trap. The purpose of this trap is to speed up the process of extraction and to reduce fire risk.

All-glass water still. This still will be shown with an improved form of steam trap.

Sleeves for joints. Teflon sleeves have been developed for use on ground glass joints as an alternative to greasing them when this is undesirable.

Spherical joint clips and spring loaded taps. Examples of these new, simple and inexpensive clips will be shown.

Marconi Instruments Ltd., St. Albans, Hertfordshire

This company is exhibiting a number of telecommunications test instruments, mostly of new design, and a representative selection of industrial electronic instruments.

Signal generators. The type TF801B generator has a range of 10 to 500 Mc/s and provides a calibrated source e.m.f. continuously variable from 0·1 μV to 0·5V under all conditions. The frequency modulated generator, type TF1077, covers 19·7 to 102·5 Mc/s; it includes a precision piston attenuator which allows the open-circuit output to be set to any level between 200 mV and 0·2 μV; the source impedance is 50 Ω. The f.m/a.m generator, type TF995A/1, covers a frequency range of 2 to 216 Mc/s in five bands and has an output level range of 0·1 μV to 200 mV. The u.h.f. generator, type TF1078, covers the frequency range 960 to 1250 Mc/s in one continuous band; it incorporates a high-quality piston attenuator and has an effective output impedance of 50 Ω.

Frequency measuring instruments. The e.h.f. wavemeter, type TF1034, is a double-cavity instrument designed for the measurement of frequencies in the range 32 000 to 32 500 Mc/s. The series of portable frequency meters, type TF1026, comprises four direct-reading, absorption type frequency meters which together cover the range 250 to 4000 Mc/s.

Inductance bridge. The 1000 kc/s inductance bridge, type TF301 F, is an a.c. mains operated instrument for the measurement or comparison of inductances from 0·01 to 50 μH and the absolute accuracy, using the calibration data supplied, is better than ± 2% ± 0·05 μH.

Other instruments. Among other instruments will be a 100 dB step attenuator, a valve voltmeter, a high-speed oscilloscope with a time of rise down to 0·01 μs, an r.f. test set, transmission measuring instruments, and moisture and pH meters.

Mine Safety Appliances Co. Ltd., Queenslie Industrial Estate, Glasgow, E.3

Combustible gas alarm. This gas alarm is designed to analyse air continuously for the presence of combustible gases or vapours up to the lower explosive limit of the material in the air. It is adaptable to analysing above this limit by the provision of a special flow system. Upon detecting the combustible constituents for which it has been calibrated it gives an accurate indication of the degree of the concentration.

Combustible gas indicators. A range of models called Explosimeters for indicating the presence of explosive mixtures of gases will be shown.

Instruments for measuring toxic gases. In these devices a sample of the atmosphere is drawn over specially prepared chemicals by means of a rubber aspirator bulb. The length of the stain caused by the chemical action of the toxic gas on the chemical packed in the tube is measured on a scale graduated in concentration. They are available for hydrocyanic acid gas, hydrogen sulphide, various aromatics and sulphur dioxide. The carbon monoxide detector is similar, but the instrument provides a measurement of shades of green on a colorimetric scale.

Murex Ltd. (Powder Metallurgy Division), Rainham, Essex

Sintered permanent magnets. A range of Multipole anisotropic, annular, sintered magnets and others of various shapes and sizes for use in the electronics and instrument industries will be shown. The range of Sincomax magnets, in which the soft iron pole piece is sintered together with the magnetic alloy as an integral unit, has been extended to include the smaller "centre pole" type of magnet which will be exhibited.

Rare metal parts. Many fabricated parts in pure tungsten molybdenum, tantalum and zirconium will be shown, together with recently produced pure niobium sheet and tube

Nash and Thompson Ltd., Oakcroft Road, Tolworth, Surrey

Resistance analogue for gas flow calculations. An instrumen designed to assist in the solution of distribution problem encountered in the design of complex towns gas network will be exhibited. The flows, pressures and pressure drop around the distribution network are simulated in an electrica resistance network.

Vapour pressure recorder. The Reid vapour pressur recorder has been developed from a prototype designed by The Billingham Division of Imperial Chemical Industries Ltd It affords a means of automatically recording alternately the values of Reid vapour pressure of petroleum fractions comin from one or two sources.

Crystalline and plastic scintillators. Additions to the firm's range of scintillators will be shown fluorescing to the radiation of an ultra-violet source.

New plastic phosphors to be shown are the mixed phosphor *p*-terphenyl plus tetraphenyl butadiene, *p*-terphenyl plu diphenyl hexatriene and diphenyl oxazole in both polystyrene and polyvinyl toluene. Sodium iodide and anthracene crystal having a variety of shapes and sizes will also be shown.

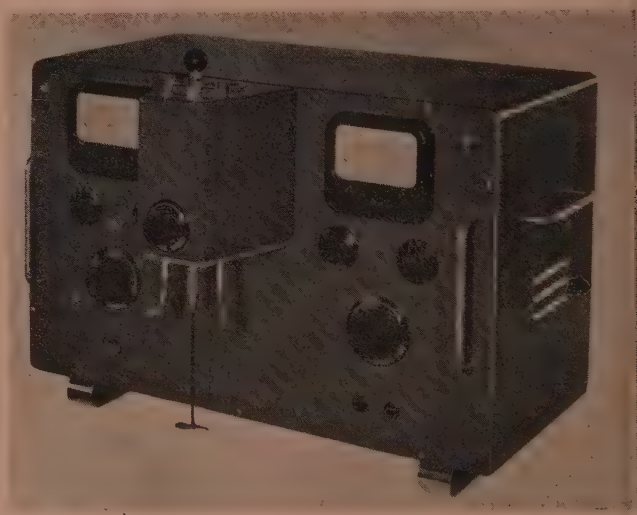


Fig. 8. Cabinet model electrolytic polisher

Electrolytic polisher. Models of the electrolytic polishe to be shown include both the standard types, the cabine model (Fig. 8) and that with the free standing head, togethe with a new model under development designed for hig speed operation, which incorporates a pump for circulatin electrolyte past the specimen to be polished. These are fo the electro-polishing of specimens for metallurgical examination.

egretti and Zambra Ltd., 122 Regent Street, London, W.1

rocess controllers. A range of industrial process controllers nd ancillary equipment will be shown.

Other exhibits. Various types of pyrometers and thermoeters, hygrometers, manometers and aeronautical and eteorological instruments will also be on view.

. A. Norgren Ltd., Pneumatic Products, Shipston-on-Stour, /arwickshire

ompressed air apparatus and ancillary equipment. A comrehensive range of filters, purifiers, and pressure regulators or a compressed air supply will be shown, and also the inge of lubricators for use where cylinders and valves, etc., equire just a small amount of lubricant for their correct peration. Particular emphasis will be placed on the air urifier, Model 2AP, which supplies extra-clean, extra-dry air nd on the precision pressure regulator, Model 11 400, which ffers good control of air pressures at low flow by means of a ompact and low-priced unit.

The functioning of the various models and their application instruments will be demonstrated.

. Oertling, Ltd., Cray Valley Road, St Mary Cray, Orpingon, Kent

alances. A range of chemical, analytical, micro-chemical, ssay and torsion balances and precision weights will be isplayed. Amongst these will be two advances in balance esign; the Releas-o-matic, having automatic control of beam elease, and the new models 146 and 147 riderless, microhemical balances.

A new student's balance will be shown together with autoatic, direct-reading, heavy-duty balances, models 70 and 71, aving capacities of 2 kg and sensitivities of 50 mg and 100 mg espectively.

adiovisor Parent Ltd., 1 Stanhope Street, London, N.W.1

hotocell applications. The exhibits will consist of various evices employing the firm's photocells. They include an dustrial smoke indicator, flame failure equipment, temerature control devices, automatic lighting controls, and ounting and batching equipment.

Hopper level controls. An electronic control will be emonstrated for use on conveyor and hopper systems dealing ith coal, fertilizer, limestone and a variety of other materials nd liquors. Units are available to provide top and bottom vel control and a number of electrodes have been designed suit various applications of this device which works by ontact only, not requiring float switches.

he Record Electrical Co. Ltd., Broadheath, Altrincham, Cheshire

lectrical indicating and recording meters. A range of the rm's Cirscale instruments including the new Series A having 240° deflexion and a 3½ in. platform dial will be shown ogether with its series H hermetically sealed instruments ith 4 or 6 in. dials, Graphic recording ammeters, voltneters, wattmeters and frequency recorders. A clip-on ansformer for use with the Graphic recorder will be xhibited; it has seven current ranges up to 600 A.

Moving coil relays. Sensitive relays for overspeed, overurrent, reverse current, undervoltage, etc., will be on show, ogether with a number of accessories.

Recorder Charts Ltd., Clyde Vale, Dartmouth Road, London, S.E.23

Recorder charts. A range of charts produced for the leading British instrument makers will indicate the service which is offered to manufacturers of recording instruments whether their requirements are for rolls, circular charts or sheets. Production methods have been devised to reduce the initial cost of producing new charts and representatives will be available to advise on new designs and suggest ways in which to avoid or reduce block or tool charges.

Charts for conventional ink recording are printed on specially stable papers which ensure minimum expansion and contraction through varying degrees of humidity. In addition, special inkless papers are available for recording with heat, pressure or electric current.

The Royal Sovereign Pencil Co. Ltd., 54 Neasden Lane, London, N.W.10

Special pencils. The exhibits will include the new thin hexagonal coloured pencil, Wolff's Crayonette, which has great toughness and depth of colour and which will be of interest to drawing offices. The Ferroprint pencil which has special opaque properties thus enabling photoprints to be made direct from the pencil drawing will also be shown in addition to the Chinagraph pencil for marking glass, metal, etc.

W. H. Sanders (Electronics) Ltd., 48 Dover Street, London, S.W.1

Microwave equipment. A range of microwave instruments and equipment will be on view, some of which are to the designs of the Radar Research Establishment of the Ministry of Supply.

Standing wave meter. This instrument (Fig. 9) (type SWM. 16/1) is designed to achieve an absolute accuracy of measurement better than 0·5% impedance over the frequency range 8·2–12·5 kMc/s. It is designed to provide r.f. output on a type N coaxial connector. Alternatively, by using a coaxial crystal detector, d.c. output may be obtained. The probe length is fixed and the coupling to the waveguide is about 23 dB.

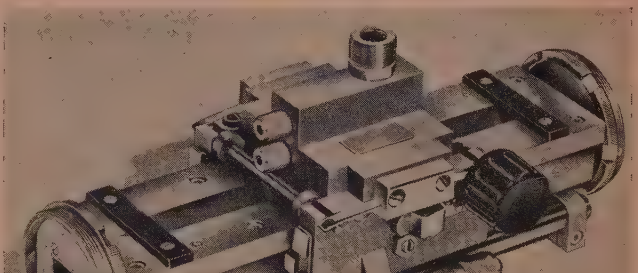


Fig. 9. Standing wave meter for use in the X band region

Calibrated attenuator. This instrument (type CA. 16/1) is intended for use in the frequency range 8·5 to 10 kMc/s. As normally supplied, a metallized glass attenuator element is fitted and calibration curves are supplied at frequencies of 8·5, 9·0, 9·5 and 10 kMc/s. The maximum calibrated attenuation is 40 dB with an absolute accuracy of 0·05 dB and a relative accuracy of 0·02 dB.

Smiths Industrial Instruments Ltd., Chronos Works, North Circular Road, London, N.W.2

Recorders. Two main types of recorders will be shown. The Desynn electric recorder is for the collation of information from up to six different sources, of functions such as: angular position, fluid level, force, linear position, differential pressure and pressure. The Tachometric recorder is for use with Smiths R.S.G. range of generators for the indication of rotational speeds.

Tachometers. Also on show will be the series M tachometry. The generator and indicator are extremely robust and suitable for the arduous conditions normally met with in rail traction. The range available is similar to existing Smiths indicators.

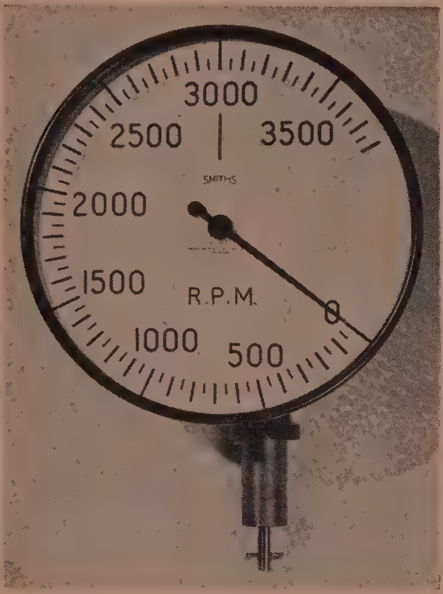


Fig. 10. Heavy duty, angle type, magnetic tachometer (12 in.) with platform scale for reduction of parallax

Another new range of instruments will be the 8, 10 and 12 in. heavy duty, angle type, magnetic tachometers for use in power stations and heavy diesel engine applications, Fig. 10. Seven figure counters can also be added when required.

Other instruments. Many other instruments will be shown, for example: electric and magnetic revolution indicators, electric and vapour pressure thermometers, hobs and cutters, escapements, gauge mechanisms, pressure warning switches, hysteresis motors, Aysynn and signal Aysynn systems of remote indication, counters, pressure and vacuum gauges, engine service counters and meters, megawatt indicators, chronocounters, hand tachometers, stop watches, Petro-flex flexible tubing, etc.

The Solartron Electronic Group Ltd., Solartron Works, Thames Ditton, Surrey

Oscilloscopes. The exhibits will include several cathode-ray oscilloscopes such as the constant bandwidth Solascope (type CD.514) for ~~5 c/s~~ to 10 Mc/s (3 dB), the general purpose Solascope (type CD.513) ~~for a~~ bandwidth from d.c. to 11 Mc/s and the type CD.518 oscilloscope based on the Radar Research Establishment type CT. 316.

Signal generators. The model GO.511 square wav generator at spot frequencies of 1 Mc/s, 100 kc/s and 10 kc/ and the pulse generator (type OPS.100C) for spot frequencies between 50 c/s and 10 kc/s will be on show.

Non-destructive testing apparatus. A set of apparatus for testing non-ferrous metals by the eddy current method will be demonstrated.

High-speed grinding equipment. This equipment comprises a variable frequency, three-phase oscillator which, together with amplifiers, provides 300 W output and drives a motor at between 12 000 and 92 000 rev/min.

Other instruments. Among other instruments to be shown will be a transfer function analyser, a dBm feedback volt meter, a power supply sub-unit, and a klystron unit, a voltage standing-wave, ratio indicator and a wide band attenuator.

Southern Instruments Ltd., Frimley Road, Camberley, Surrey

Engine indicator equipment. The Minirack engine indicator equipment (type ME 112) which will be on show is a single channel, trolley-mounted, electronic device with universal recording facilities. It is intended for use with internal com bustion engines or compressors and employs capacitor resistance, electromagnetic or photocell pick-ups. The camera takes still or continuous records of the 6 in. diameter cathode-ray tube which is used with an illuminated graticule.

Transient recorder. The transient recorder (Minirack type TR 12) which will be exhibited is a cathode-ray oscillograph for recording high-speed transients with a single-stroke time base. The voltage signal to the oscillograph automatically turns on the spot, starts the time-sweep and produces the deflexion that is photographically recorded. A hard-valve time-base circuit is used. A number of special features have been incorporated.

Continuous-feed cameras. Cameras using 70 or 120 mm unperforated film or paper in 200 ft rolls designed for use with oscilloscopes are to be shown. The chief features are the four-speed gear box, the automatic record numbering device, daylight loading cassettes, preset and unexposed footage controls and facilities for remote operation.

Automatic developer. The type M.732 electrically-operated auto-developer will develop, fix and dry any type of oscillo graph recording paper in either short or long lengths and any width up to 120 mm. It operates at 1 in./s. The record is dried immediately after fixing, and although there is no intermediate washing stage, the record is sufficiently perma nent not to discolour for long periods. The power required is 1·3 kW at 200–240 V, 50 c/s.

Sunvic Controls Ltd., 10 Essex Street, Strand, London, W.C.2

Process control instruments. The complete range of Nullmatic industrial process control instruments will be exhibited including working demonstrations; the exhibits will include several new instruments notably a "plug-in" controller and miniature panel control station, a new miniature pressure regulator, an improved valve positioner and additions to the pressure transmitter range. A leak detector which is a production tool of particular interest to those concerned in the detection of minute leaks in castings, etc., will also be shown.

Other instruments. A new industrial batch counter having several unique features will be demonstrated and a pulse height analyser will be shown, together with many other instruments in the Sunvic range including electronic recorders, a d.c. amplifier, resistance thermometer controllers, thermo stats, relays and time delays.

aylor Electrical Instruments Ltd., Montrose Avenue, Slough, uckinghamshire

apacity-resistance bridge. Model 110C, which will be xhibited, covers a range of capacities from zero up to 200μF in eight steps and resistances from zero up to 20 MΩ also in eight steps. Balance is indicated by a magic ye.

Electronic test meter. Model 171A is basically a valve oltmeter; the alternating voltage covered is 1–250 V at 0 c/s to 200 Mc/s and the direct voltage range is 1 V–25 kV. he resistance range is zero up to 1000 MΩ in six steps. here are five output ranges of − 25 to + 3 dB.

he Tintometer Limited, The Colour Laboratory, Waterloo oad, Salisbury

olour measuring instrument. A new version of the Lovibond chofield Tintometer will be shown. This is a visual colour easuring instrument which enables readings to be taken on ny colour directly against actual colour filters, so that it is xtremely simple to use. The readings are then instantly onverted into the terms of the international system. The nstrument is especially suitable for use where specifications re issued in terms of the C.I.E. nomenclature.

ownson and Mercer Ltd., Croydon, Surrey

emperature-controlled baths, ovens and hotplates. A range f accurately controlled hotplates, ovens, water baths and ther thermostats will be exhibited.

Cryostat. This device incorporates two large vacuum-acketed glass tanks, in one of which either a refrigerator coil r solid carbon dioxide together with a heat exchanger is laced, and in the other a duplex immersion pump with ontrol gear. The temperature of the bath itself is maintained y varying the input through the heat exchanger by means of a pecial thermostat. Consumption of 3 oz of solid carbon ioxide per hour at − 72° C gives an indication of its efficiency; e principle can be applied to all uses below room temperaure. The vacuum-jacketed glass bath has windows for bservation of viscometers or other apparatus, and these do ot ice up even at − 70° C.

Improved Warburg apparatus. This apparatus can be used or all reactions where gas evolution needs to be known while sample is shaken under constant conditions. In this nstrument every sample with its attendant gas measuring anometer is shaken about its vertical axis by a spring ovement. This gives silent operation and any sample may e stopped at will, merely by holding it. The bath is circular nd the whole of it can be rotated on a ball race to bring any anometer in front of the operator. The latest immersion ump and regulator enables much smaller quantities of water o be used with much quicker rates of heating and stabilizaon. Temperatures are controlled to ±0·01° C at 37° C.

he Ultrasonoscope Company (London) Ltd., Sudbourne Road, rixton Hill, London, S.W.2

ltrasonic flaw detection apparatus. New ancillary equipment nd techniques for ultrasonic flaw detection will be shown in onjunction with the latest model of the Ultrasonoscope. mprovements in the instrument itself include the use of a ost deflexion accelerator tube which has virtually doubled e length of the time base, the incorporation of the *Y*-shift ontrol within the instrument, and development for operation t 5 Mc/s for the examination of fine-grained materials, nmersion testing and examination for microporosity.

The exhibits will include variable-angle, low-frequency probes designed for use on coarse-grained materials; new transverse wave probes for use on sections down to $\frac{1}{16}$ in.; immersion testing apparatus for the rapid scanning of large areas; ultrasonic delay lines using nickel tube and calibrated directly in microseconds.

Unicam Instruments Ltd., Arbury Works, Cambridge

Flame photometer. In this flame photometer, Fig. 11, an air supply at 24 lb/in.^{2} operates a concentric-jet atomizer which feeds a burner using either propane or acetylene, depending on the flame temperature required. Pressure gauges and controls are located in the atomizer compartment with funnel feed to the atomizer mounted on the front panel. The apparatus in contact with the sample is made of glass. Light from the burner passes into a monochromator based on the compensated spherical mirror design described by Czerny which gathers a high proportion of the incident light. A fused silica prism is used which, in conjunction with a photomultiplier and a lead sulphide cell, is suitable for measurements from 250 mμ to 2·7 μ. Wavelength selection is made by varying the angle of the Littrow mirror. Other controls vary slit width, dark current and sensitivity. Radiation leaving the exit slit is chopped at 100 c/s and focused by a concave mirror to the selected detector. The use of chopped radiation ensures good zero stability. A homodyne rectifier (with phasing pulses taken from the chopper disk) converts the a.c. output to a d.c. signal. Readings are taken directly from a spot galvanometer which may be connected to a recorder if required.

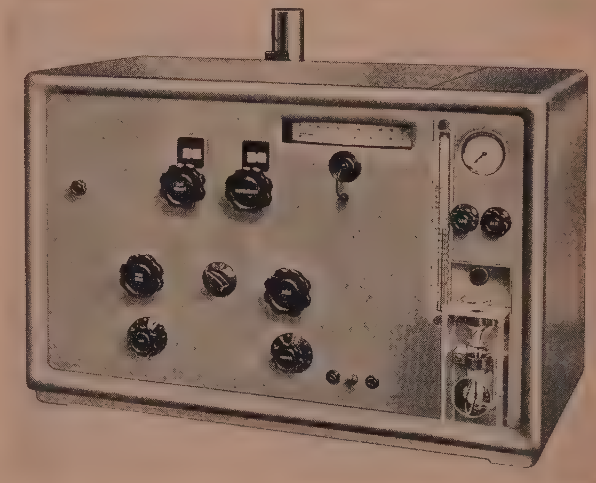


Fig. 11. Flame photometer

Crystallographic equipment. Examples of the firm's range of X-ray diffraction and other crystallographic equipment will be on show.

Spectroscopic apparatus. The exhibits will include infrared spectrometers and a range of ultra-violet and visible spectrophotometers.

United Trade Press Ltd., Boswell House, 9 Gough Square, Fleet Street, London, E.C.4

The second edition of the *Instrument Manual* and other books on instruments published by this firm will be on view together with copies of its monthly *Instrument Practice* which covers automation, control and measurement.

Walker, Crosweller and Co. Ltd., Cheltenham, Gloucestershire

Telemetering instruments. The new transmission systems called the Arkon method of telerecording will be shown; it provides chart recording, continuous indication, and integration and is particularly suitable for the gas industry.

Recorders. A full range of Arkon gas flow, pressure and vacuum recorders will also be on show.

W. Watson and Sons, Ltd., 313 High Holborn, London, W.C.1

Microprojector. This instrument has been designed for the efficient projection of microscope preparations by transmitted light at screen magnifications of up to approximately 5000 diameters. Excellent image brilliancy is maintained for a picture diameter of 8 ft. at projection distances as great as 40 ft. Selection of the objective magnification is made by single control which ensures at each magnification stabili of focus, no change in picture centre and optimum illumin tion. A specially designed illuminating system has been us ensuring a steady, bright and evenly illuminated field at a magnifications. Except for a control unit supplying the lig source, and which may be at a convenient distance from t microprojector, the instrument is entirely self-contained a enclosed. By the extensive use of aluminium alloys and t special system of illumination, a compact unit of minimu weight has been evolved with no loss in strength and rigidit Lens surfaces are coated to increase light transmission a to improve image contrast.

Mechanical stages and microscopes. It is also hoped t show some new designs in mechanical stages and a full rang of microscopes.

Notes and comments

Prizes for original contributions published in this Journal

The Board of The Institute of Physics has awarded the following Bowen Prizes for papers published in last year's volume of this *Journal.*

Dr. K. P. Norris, of the Wheatstone Physics Laboratory, King's College, London, for his paper on *A reflecting microscope for infra-red absorption measurements* (p. 284, August 1954). A prize of twenty guineas.

Mr. G. Revesz, of the British Rayon Research Association, Manchester, for his paper on *An autocorrelogram computer* (p. 406, November 1954). A prize of fifteen guineas.

Mr. J. H. Welch, of the Building Research Station, Watford, Herts, for his paper on *A simple microscope attachment for observing high-temperature phenomena* (p. 458, December 1954). A prize of fifteen guineas.

These prizes are awarded to authors who are not more than 35 years of age and whose papers are judged to be the best in respect of originality, scientific value, practical utility to instrument makers and users, and presentation including the standard of presentation of the manuscript. Money for prizes is provided by the Scientific Instrument Manufacturers' Association of Great Britain Ltd., from the Bowen Trust Fund established by the late Mr. William Bowen.

Lectures and meetings at The British Instrument Industries' Exhibition

The following arrangements are announced in connexion with The British Instrument Industries' Exhibition (see p. 234).

2.30 p.m., 29 June. *Instrumentation as an aid to fuel efficiency*, lecture by Mr. R. Clare.

2.30 p.m., 30 June. *Instrumentation and nuclear energy with applications*, lecture by Dr. Denis Taylor.

2.30 p.m., 1 July. General meeting of The Society of Instrument Technology to which all visitors to the exhibitio are invited.

2.30 p.m., 4 July. *Future applications of digital computor* lecture by Mr. H. McGee Rose.

2.30 p.m., 5 July. *Photocopying and reproducing in industr* paper by Messrs. H. R. Verry and A. B. Baker.

11.0 a.m., 6 July. Lecture on *Instruments in steam raising* (Provisional.)

2.30 p.m., 6 July. Lecture on *Instruments in the utilizatio of steam.* (Provisional.)

11.0 a.m., 7 July. Lecture on *Instruments in the figh against smog.* (Provisional.)

Secretaries of associations who wish to organize parties t visit the exhibition and attend any of these conferences ma obtain free admission by writing to the Organizers, F. W Bridges and Sons Ltd., Grand Buildings, Trafalgar Square London, W.C.2, stating the number of tickets required an the date of the intended visit.

British Journal of Applied Physics

Contents of the June issue

SPECIAL ARTICLE

Electronic fluctuations in semiconductors. By R. E. Burgess.

ORIGINAL CONTRIBUTIONS

A replica technique for "reflexion" electron microscopy. By D. E. Bradley.
Conditions for aperiodicity in linear systems. By A. T. Fuller.
Rheological behaviour of continuously sheared polythene. By W. F. O. Pollet
Forming procedures for silicon point-contact transistors. By J. W. Granvill W. Bardsley and A. F. Gibson.
Measurement of the statistical time lag of breakdown in gases and liquids. B R. F. Saxe and T. J. Lewis.
Indium antimonide as a fluxmeter material. By E. W. Saker, F. A. Cunnell an J. T. Edmond.
The disturbance of stress in an infinite plate by a lemniscate-shaped hole. B W. Snowdon.

NOTES AND NEWS

Correspondence

Motion of water droplets of an emulsion in a non-uniform field. From C. Bezem and G. A. Croes; C. A. R. Pearce.

Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principles, construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Square, London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation of contributions.* (Price 2*s.* 6*d.* including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon application from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, London, E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within 60 days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of address or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £4 per volume ($11.50 U.S.A.), including index (post paid) payable in advance. Single parts, so far as available, may be purchased at 8*s.* each ($1.15 U.S.A.), post paid, cash with order. Orders should be sent to The Institute of Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

The Physical Society's Exhibition—London, 1955

By S. S. Carlisle, M.Sc., A.M.I.E.E.

The new devices, instruments and materials exhibited are briefly described and some of the improvements in well-known pieces of apparatus mentioned.

ne 39th Physical Society Exhibition of Scientific Instruments d Apparatus was held this year in the New Hall of the oyal Horticultural Society in London. It was the first time its history that the exhibition has been held outside its rthplace—The Imperial College of Science and Technology. any will feel sorry that it was not possible to continue olding the exhibition in surroundings so appropriate to its iginal character, but it must be admitted that the nature the exhibition has radically changed with the progress ade in apparatus and techniques employed in scientific search, and in many ways the new surroundings are better ited for an exhibition of this kind.

If it is accepted that the objective of the exhibition is the me as in its original conception, i.e. to display to those rectly or indirectly concerned with scientific research new chniques in research and experimental procedure with articular emphasis on measurement, then this exhibition and ose of recent years may be severely criticized in that they e becoming too much a display of the products of the ritish instrument-making industry. This criticism is further stified by the recent introduction of the British Instrument dustries Exhibition. On the other hand, the research orker is now much more dependent on the supply of complex struments and equipment in order that he may carry out ficiently his particular investigation and he is often forced use equipment the design and functioning of which is quite nfamiliar to him. Unlike his fellows of a generation ago, often cannot and should not fashion his own tools, lthough it is hoped that he is properly trained in their use nd limitations. From this point of view a full display of e "boxes of mystery" with only a statement of their purpose nd performance is of great value to many concerned with ndamental and applied research. However, too many xhibits are justified as "new" on the grounds of minor anges in design and performance and too many instruments a similar type are shown on the one stand, where one odel of a particular range and some literature would serve dequately. Besides causing congestion this cramming in of xhibits makes it difficult for the visitor to see quickly the ings he hopes to spot at a scientific exhibition. The rganizers might well consider more severe censorship of xhibits in future.

This year's exhibition still further emphasizes the following atures of modern research practice: (*a*) widespread use of ectronic devices; (*b*) the rapid development and provision of -, gamma- and beta-radiation measuring devices and their pplication in research and industry; (*c*) the very compre-ensive range of laboratory equipment now available to aid e research worker.

In reviewing the exhibits which seem noteworthy for novelty technique, improvement on previous standards, or for their eneral interest in research or industrial practice, I shall consider them under the headings of "Research and analytical tools," "Industrial instruments and equipment," "Sundry devices and components," and "Materials." For full details of the exhibits the reader is referred to the exhibition handbook, copies of which are still available from The Physical Society, 1 Lowther Gardens, London, S.W.7, price 7*s.* 0*d.* including postage.

RESEARCH AND ANALYTICAL TOOLS

Spectrographic analysis. The present interest in the infrared spectrum and the recent production of the N.P.L. echelette replica gratings is noticeable by the number of infra-red spectrometers now on the market. Four firms showed these instruments. Sir Howard Grubb Parsons and Co. demonstrated an experimental instrument covering the range 2–15 μ. Unicam Instruments (Cambridge) Ltd., Hilger and Watts Ltd., and Mervyn Instruments Ltd. also showed grating instruments. The Mervyn spectrometer was of remarkably simple design and incorporated an ingenious method of compensation, in which the light output from the source is continuously monitored through the one detector and optical system and the gain of the amplifier is automatically adjusted to compensate for drifts in the source intensity, detector sensitivity, or amplifier characteristics. The instrument covers the range 1–4 μ.

The United Kingdom Atomic Energy Authority showed a high precision variable path length liquid cell for infra-red spectroscopy, in which the cell length can be adjusted in the range 0 to 0·015 in. with an accuracy of 0·000 02 in.

Hilger and Watts Ltd. showed a metal ratio analyser for determining the ratio of the concentration of two elements, e.g. zinc in brass. Interference filters are used to select appropriate lines in the spark spectra of the metals and the transmitted light passed to two photomultipliers. By integrating and comparing the photomultiplier currents the system can be calibrated for the metal ratio in the sample.

The Metropolitan-Vickers Electrical Co. Ltd. showed a model of their mass spectrometer suitable for metals analysis using a spark source. A mass range of 20–1 can be covered in a single exposure of the photographic plate. Electrical recording can also be employed.

Physical and chemical analysis. The present popularity of chromatographic techniques of analysis is noticeable, and although there was no mention of it at the 1954 Exhibition, there were five firms this year showing apparatus concerned with this method of analysis. Sir Howard Grubb Parsons and Co. demonstrated the use of the infra-red gas analyser as a detector in gas chromatography, where the carbon of each component coming off is oxidized to carbon dioxide.

By this means 0·005% ethylene in a 10 ml. sample of mixed hydro-carbon gases could be identified and estimated. Gas chromatography apparatus shown by C. F. Casella and Co. Ltd. used a detector which responds to very small changes in the density of the gas issuing from the column. This detector consists of a copper block drilled out to form a network of gas flow channels equivalent to a Wheatstone bridge. A comparison gas is also fed into the network and any change in density of the column gas causes a cross flow in the network which is detected by a sensitive thermo-electric flow detector. Apparatus by Metropolitan-Vickers Electrical Co. Ltd. used a thermal conductivity detector. For liquid chromatograp analysis, ingenious automatic fraction collecting appara was shown by J. W. Towers and Co. Ltd., The Uni Kingdom Atomic Energy Authority and A. Gallenkamp a Co. Ltd.

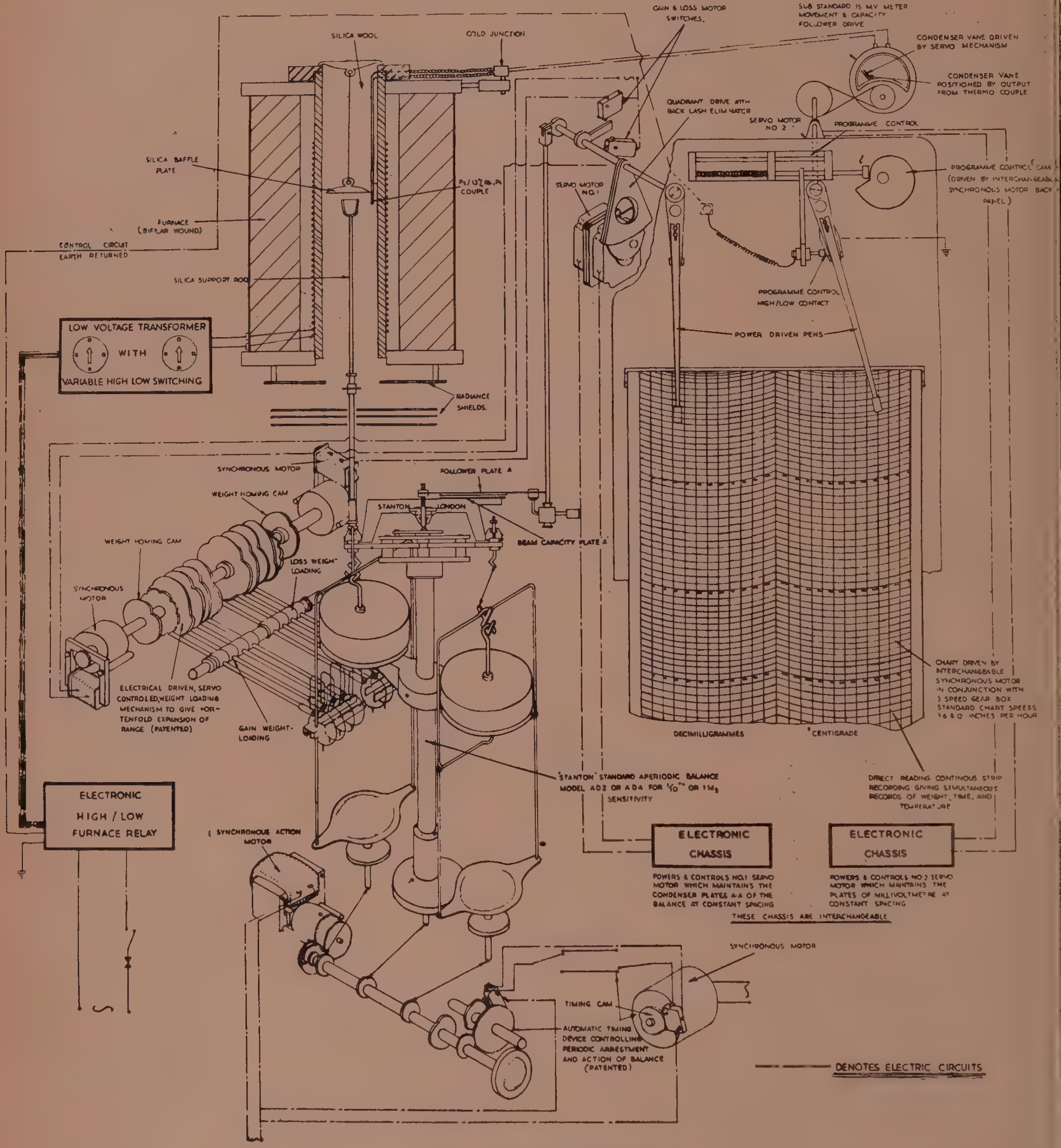

GAIN & LOSS MOTOR SWITCHES.
SUB STANDARD IS M.V. METER MOVEMENT & CAPACITY FOLLOWER DRIVE
SILICA WOOL
COLD JUNCTION
CONDENSER VANE DRIVEN BY SERVO MECHANISM
CONDENSER VANE POSITIONED BY OUTPUT FROM THERMO COUPLE
QUADRANT DRIVE WITH BACK LASH ELIMINATOR
SERVO MOTOR NO 2
PROGRAMME CONTROL
SILICA BAFFLE PLATE
Pt/13% Rh.Pt COUPLE
SERVO MOTOR NO. 1
PROGRAMME CONTROL CAM (DRIVEN BY INTERCHANGEABLE SYNCHRONOUS MOTOR BACK PANEL)
FURNACE (BIFILAR WOUND)
CONTROL CIRCUIT EARTH RETURNED
SILICA SUPPORT ROD
PROGRAMME CONTROL HIGH/LOW CONTACT
POWER DRIVEN PENS
LOW VOLTAGE TRANSFORMER WITH VARIABLE HIGH LOW SWITCHING
RADIANCE SHIELDS.
SYNCHRONOUS MOTOR
FOLLOWER PLATE A
WEIGHT HOMING CAM
STANTON LONDON
WEIGHT HOMING CAM
BEAM CAPACITY PLATE A
LOSS WEIGHT LOADING
SYNCHRONOUS MOTOR
CHART DRIVEN BY INTERCHANGEABLE SYNCHRONOUS MOTOR IN CONJUNCTION WITH 3 SPEED GEAR BOX STANDARD CHART SPEEDS 1 6 & 12 INCHES PER HOUR
ELECTRICAL DRIVEN, SERVO CONTROLED WEIGHT LOADING MECHANISM TO GIVE FOR-TENFOLD EXPANSION OF RANGE (PATENTED)
GAIN WEIGHT-LOADING
DECIMILLIGRAMMES
°CENTIGRADE
'STANTON' STANDARD APERIODIC BALANCE MODEL AD2 OR AD4 FOR 1/10 OR 1 Mg SENSITIVITY
DIRECT READING CONTINOUS STRIP RECORDING GIVING SIMULTANEOUS RECORDS OF WEIGHT, TIME, AND TEMPERATURE
ELECTRONIC HIGH / LOW FURNACE RELAY
SYNCHRONOUS ACTION MOTOR
ELECTRONIC CHASSIS
POWERS & CONTROLS NO.1 SERVO MOTOR WHICH MAINTAINS THE CONDENSER PLATES A-A OF THE BALANCE AT CONSTANT SPACING
ELECTRONIC CHASSIS
POWERS & CONTROLS NO 2 SERVO MOTOR WHICH MAINTAINS THE PLATES OF MILLIVOLTMETRE AT CONSTANT SPACING
THESE CHASSIS ARE INTERCHANGEABLE
SYNCHRONOUS MOTOR
TIMING CAM
AUTOMATIC TIMING DEVICE CONTROLLING PERIODIC ARRESTMENT AND ACTION OF BALANCE (PATENTED)
DENOTES ELECTRIC CIRCUITS

Fig. 1. The thermo-balance

For the determination of the residual trace elements, su as aluminium, titanium, vanadium and zirconium in st solutions, the main components of iron, chromium and nic can be conveniently separated out by mercury cath electrolysis leaving the trace elements in solution, and t more easily determined. Improvements in this technique paration have been made by the British Iron and Steel search Association to give high rates of removal of the thodically deposited elements, and electrolysis apparatus signed according to this work was shown by Baird and tlock Ltd. and Griffin and George Ltd.

Classical polarographic techniques are inadequate for termining the concentration of either a metal ion in the esence of larger concentrations of metal ions which are duced at more positive potentials, or two metal ions whose lf-wave potentials are so close together that their waves alesce. Such difficulties can largely be overcome by super-posed a.c. polarography but the use of this method is nited by a relatively large component of a.c. arising from e double-layer capacity of the mercury/solution interface. is problem of condenser current has been overcome in the uare-wave polarograph designed by G. C. Barker and I. L. nkins of the Atomic Energy Research Establishment, arwell, and manufactured by Mervyn Instruments Ltd. uring the square-wave period the diffusion current remains actically constant, but the condenser current rapidly decays a negligible value since the capacity and total series resis-nce of the cell behaves as a differentiating network with a ort time constant.

Among the many chemical balances exhibited mention ight be made of the thermo balance by Stanton Instruments d. which simultaneously records changes of weight and mperature against time. Fig. 1 shows the balance system. ne furnace is designed to work at up to 1000° C. The eight is recorded by a servo-driven pen, the action of which initiated by an electrical capacity detector system fitted to e balance arm, so that the servo follows faithfully small ovements of the balance arm without reacting on it. The rvo mechanism also automatically applies or removes eights when the balance arm reaches the end of its move-ent. A weight change of ±1 g can be followed auto-atically with an accuracy of 1 mg. Cams are fitted so that e furnace heating can be controlled according to a required ogramme. The balance has obviously many applications in avimetric analysis.

For the analysis of a composite gas, Sir Howard Grubb rsons and Co. showed a method in which the velocity of opagation of a sonic frequency pressure wave in the gas is ed to measure its density, and thus in certain circumstances n be calibrated for composition. The propagation time is easured in relation to that in air by measurement of the ase difference between the transmitted and received essure waves travelling down a sampling tube of fixed ngth. The United Kingdom Atomic Energy Authority also owed this method of analysis of a binary gas mixture, but ed the resonant frequency in the sample chamber for termination of the velocity of propagation, and hence gas mposition.

Measurement and use of X, gamma and beta radiation. The antity of nucleonic equipment exhibited was a clear dication that we are living in the atomic age. For radio-tivity measurement the scintillation counter now seems to most popular, except where for reasons of economy or herwise the simpler ionization chamber or Geiger–Müller unters are preferred. The associated equipment, including alers, rate meters, pulse height discriminators and analysers d stabilized h.t. supplies are rapidly becoming unified in sign. For example, Isotope Developments Ltd. showed a neral purpose unitized counter equipment, including a rtable scintillation counter head, wide band amplifier, gle channel pulse analyser, scaling unit, rate meter and high stability e.h.t. supply. Labgear (Cambridge) Ltd. showed a very sensitive scintillation counter for low activity gamma isotopes in powder or liquid forms using a 1% thallium activitated sodium iodide phosphor. The United Kingdom Atomic Energy Authority showed a range of crystal and plastic phosphors for scintillation counters. The Twentieth Century Electronics Ltd. showed neutron counter tubes using enriched boron trifluoride gas and another type in which indium is incorporated as the cathode of a Geiger-counter so that after neutron irradiation the beta activity induced in the indium is counted *in situ*. Sunvic Controls Ltd. showed a pulse height analyser capable of sorting pulses into as many as 120 different amplitude groups and at an incoming rate of 1600 pulses per second. The pulse amplitude spectrum is displayed on a cathode-ray tube in the form of a raster of vertical lines with one line for each amplitude group, and the count of each group is shown on a binary scale by an array of brightened dots. Fig. 2 shows the display.

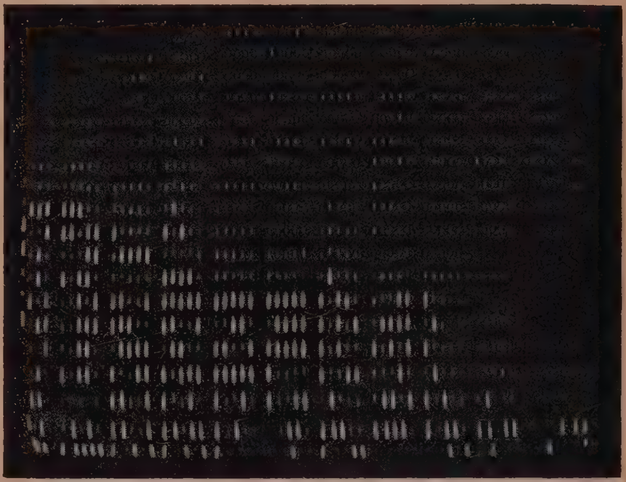


Fig. 2. The pattern on the display tube of a pulse height analyser

For more classical methods of radiation measurement the beta electroscope shown by H. Tinsley and Co. Ltd. is of interest. A quartz fibre "hair pin" placed near to an attracting electrode is the indicator. The attracting electrode is connected to a collector electrode in the ionization chamber containing the sample. The rate of discharge of the hair pin is proportional to the strength of the source and is measured by timing its travel under a microscope objective.

An X-ray shadow microscope was shown by the Cavendish Laboratory, Cambridge. Two magnetic electron lenses are used to produce a very sharply focused electron beam less than 1 μ in diameter. This strikes a thin metal foil target, so producing an intense point source of X-rays. From this source shadows can be cast on a screen which show internal detail of biological and metallurgical specimens interposed between the screen and the source. Very high magnification can be achieved according to the ratio of the distance from screen to source to distance from specimen to source.

Electronic testing apparatus. The range of testing equipment now available for work at any frequency from a fraction of a cycle per second to over 30 000 Mc/s is most impressive. Marconi Instruments Ltd. showed an e.h.f. signal generator covering the range 33 300 to 37 500 Mc/s, while at the other extreme Airmec Ltd. showed a very low frequency signal generator covering the frequency range 0·03 to 30 c/s, which is likely to be useful to servo engineers.

Much attention is being given to the development of very high speed writing cathode-ray tubes. For example, Southern Instruments Ltd. showed a transient recorder using a 10 kV cathode-ray tube capable of recording transients down to 0·2 μs in duration. Enlargement of the trace photograph enables a time interval of 0·001 μs to be resolved. Nagard Ltd. also showed a transient high speed oscilloscope capable of a writing speed of 30 cm/μs for photographic recording. Electronic Tubes Ltd. showed a cathode-ray tube with post deflection acceleration capable of display of 100 Mc/s signals.

To facilitate the study of the behaviour of thermionic valve electrode systems subjected to mechanical vibration, Electronic Tubes Ltd. showed a stroboscopic vibration test set. It provides for stroboscopic measurement under a microscope of the movement of the valve electrodes and simultaneous measurement of the resulting valve electrical output. The valve is vibrated by an electro-magnet at frequencies in the range 15 c/s to 3000 c/s at accelerations of about 10 *g*.

The Electrical Instrument Co. (Hillington) Ltd. showed a simple frequency meter employing two bridge T-networks with characteristic frequencies centred at the limits of the frequency range to be covered. Both networks are energized by the supply under test and their outputs are rectified and connected in opposition to a moving coil d.c. meter with a centre current zero and this indicates the frequency. At a frequency mid-way between the two scale limits the network outputs balance and the meter reads centre scale, in which condition the measurement is quite independent of the supply voltage. The frequency scale is linear and the instrument is relatively insensitive to signal wave form.

Particle counting systems, including blood cell counting. The general use of radioactive material and other radiation sources and the health hazards associated, has caused much attention to be given to the development of equipment for making blood counts as a check on the condition of operators in this field of work. Evans Electroselenium Ltd. showed an ingenious counter, due to P. J. Crosland-Taylor. A small quantity of diluted blood is automatically drawn up into a pre-calibrated glass capillary tube in the instrument. From this tube the blood sample moves into the counting chamber, where the blood cells enter a stream of distilled water which is accelerated toward a fine jet. This acceleration spaces out the blood cells in the liquid stream, so that they can be individually viewed and counted by a photocell under dark ground illumination conditions. The associated electronic counter is designed to work at up to 20 000 pulses per second, so providing ample allowance for any irregularity of the spacing of the cells, which normally occur at a rate of 200 pulses per second. The technique might well be applied to other particle counting problems where the particle can be suspended in a suitable liquid. In another blood cell counter by C. Baker of Holborn Ltd. the diluted blood is stained and put on an undivided haemocytometer. This is placed on a stage, which is arranged to scan in two directions under a microscope. A photomultiplier and slit system generates pulses as each image of a cell passes the field of view, and these are counted in a scaler unit. The operation is repeated with a double size slit and from the two counts registered the number of cells can be determined. Mullard Ltd. showed a particle counter and sizer using a cathode-ray tube flying spot scanner to examine a photomicrograph of the particles. The particles are counted as pulses generated by a photocell illuminated by light transmitted through the sample und inspection. A line-to-line memory system ensures that ea particle is counted only once.

Wave form analyses. Southern Instruments Ltd. show a film analyser and correlogram computer. The purpose this equipment is to compute cross correlation functions data supplied as continuous line records on film or pap Each film is joined to form a continuous loop and pass through the reading head consisting of a photoelectric li follower. In this the image of a cathode-ray tube spot automatically made to follow the recorded line, so that t deflection voltage applied to the cathode-ray tube is pr portional to the amplitude of the wave form at that insta To plot a correlogram two films are fed through two read at identical speeds and the outputs of the two line follow are multiplied together and the product integrated over t length of the loop of film. This integral is recorded and t process repeated for differing phase displacements betwe the films, so that the correlation function can be determin In addition the equipment can be used to compute mea standard deviations, histograms, etc., of data supplied in t form.

The Admiralty Research Establishments showed a mea of displaying the average distribution of the amplitude of irregular signal. The waveform under examination is appli to the Y-plates of an oscilloscope so that the spot travers a narrow horizontal slit placed in front of the screen. photocell behind this slit records the time integral of the lig received and this is a measure of the proportion of the to time the function spends in the amplitude zone defined the slit position. By moving the slit in the Y-direction curve of the amplitude distribution function can be plott This is done automatically by superimposing a low-frequen sweep on the signal, so moving the waveform relative to t slit. This sweep is also fed to the X-plates of the display tub and by applying the smoothed photocell output to t Y-plates of the display tube, the distribution function plotted.

Medical diagnosis. An interesting application of ult sonics was shown by the Institute of Cancer Research of t University of London, in which an echo locating apparat was used to investigate the relationship between characteris echoes from the human brain and the anatomical structu concerned, and thus might prove useful in clinical inve gations.

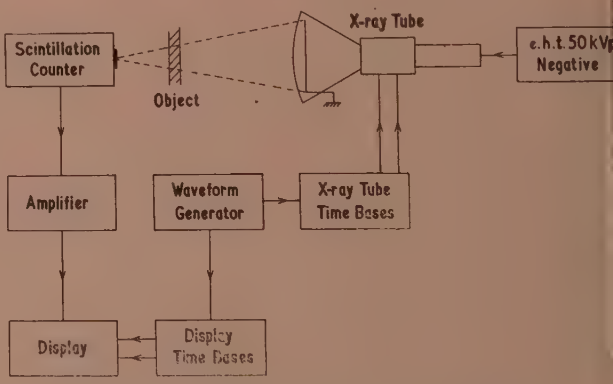


Fig. 3. The scanning X-ray tube system

For diagnostic radiology the Institute also showed a nning X-ray tube system (Fig. 3). An electron beam is de to scan a platinum foil target, so producing a point irce of X-rays which moves according to a standard 405 e interlaced television raster of amplitude 15 × 12 cm. e X-radiation is collimated by a pin hole on to an anthracene ystal scintillation counter and photomultiplier. A signal is veloped according to the counting rate and used to modulate e beam intensity of a cathode-ray tube, the spot of which made to scan the same raster as the X-ray tube. By inter- sing an object between the platinum foil X-ray target and e counter an image is produced on the cathode-ray tube presenting the X-ray absorption pattern over the area of e object. The scanning system has the advantage that better ntrast and definition can be got than with orthodox radio- aphic techniques.

Optical and photographic techniques. To obtain photo- aphic records of phenomena over very short exposure times the order of 10^{-8} s, the image convertor tube is now ailable. The tube has at one end a photo-cathode on iich the optical image to be recorded is formed. The ctron image produced is focused on the other end of the be and an intervening system of electrodes enables the ctron stream to be switched on and off by a suitable voltage lse. Recent improvements in circuit technique and pulse neration by Mullard Ltd. have now made possible exposure nes of the order of 10^{-9} s. A demonstration showed the ethod in use for study of the development of a spark dis- arge. Different stages in the formation of the spark could looked at by varying the path length by movable mirrors tween the spark and the photo-cathode.

Mullard Ltd. also showed how photo-elastic techniques can used in the study of stresses in transparent plastics which e subjected to ultrasonic vibration. A demonstration owed standing waves induced in a long rectangular section transparent plastic material and indicated how its shape d holes in the section affect the propagation of the pressure ive. The technique should be of great value in designing ructures to carry sound waves.

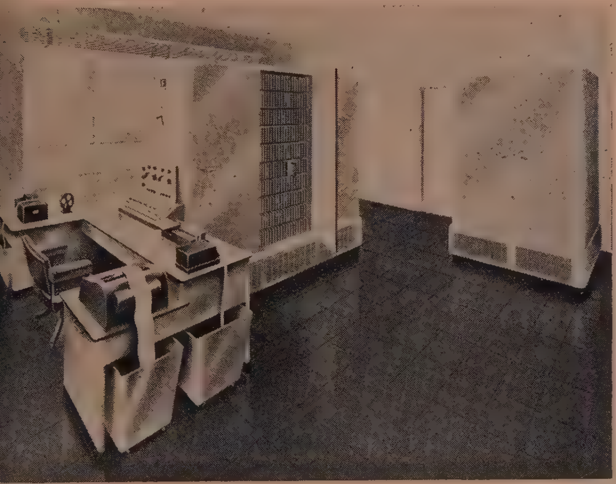


Fig. 4. The electronic computer "Pegasus"

Computers. Ferranti Ltd. showed their medium sized, neral purpose digital computer known as "Pegasus." It is ilt from standardized plug-in units for ease of maintenance and replacement. Computation takes place in an immediate access store of 43 single-word registers consisting of nickel delay lines. This is backed up by a magnetic drum store of 4096-word capacity. Fig. 4 shows the computer.

INDUSTRIAL INSTRUMENTS AND EQUIPMENT

Inspection devices. For flaw detection in large metal masses by ultrasonics, the Ultrasonoscope Co. (London) Ltd. showed a testing system in which the specimen is completely immersed in a liquid bath and the transducer head is located above it, but also below the surface of the liquid. This system has the advantage that the transducer can be moved to scan the area of the sample without risk of variation in the efficiency of contact with the specimen such as occurs in orthodox methods using thin oil films to communicate the pressure wave from the transducer to the surface under examination.

Apparatus for the assessment of the compressive strength of concrete structural units by measurement of the velocity of propagation of an ultrasonic wave in them was shown by A. E. Cawkell, Electronic Engineers, according to a design by the Road Research Laboratories.

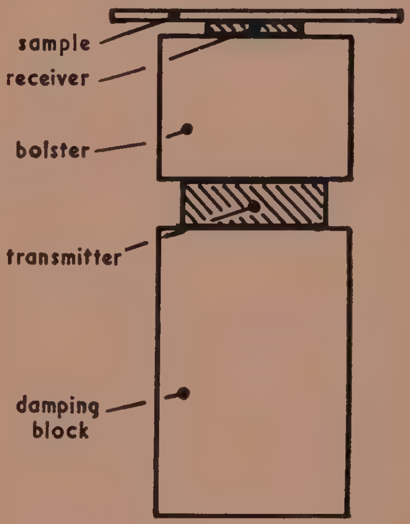


Fig. 5. The arrangement of the transducer head and specimen in the ultrasonic step function pulse technique

C.N.S. Instruments Ltd. showed an ultrasonic flaw detector which can be used with a standard Cossor oscilloscope, so economizing in equipment. They also showed a battery-operated flaw detector which would be very useful in field work. The Ultrasonoscope Co. Ltd. showed a step function pulse technique for detecting flaws in a thin sample. In this system an electrical step function is imposed on a thick barium titanate disk, which is subject to heavy mechanical damping. This transducer is applied to the surface of the sheet under study with a thin disk of barium titanate interposed as shown in Fig. 5. Thus a step function of stress is passed through the barium titanate to the sample surface and reflected back from any flaws below its surface. The signal from the thin disk of barium titanate shows a short pulse on the first passage of the step function and then an echo for any flaw below the surface. An echo pulse from flaws as little as 0·02 in. below the specimen surface can be readily identified. Kelvin and Hughes Ltd. showed an ultrasonic scanning system for flaw inspection of long specimens. The transducer is moved by a line scan across the surface and coupled with a recorder, so that positions of flaws are recorded. The usual oil film is used to maintain contact between the transducer and the surface.

For sorting certain types of coals, which differ only in surface structure, the National Coal Board's Scientific Department showed a system in which the surface of a sample is illuminated at a large angle of incidence and the light scattered from the surface is applied to a photocell *via* a rotating Polaroid disk acting as a rotating analyser. The scattered light from the coal surface is polarized to a degree depending on the structure of the surface, and thus the amplitude of the signal on the photocell, which measures the degree of polarization, can be used to sort the coals into different categories.

For the detection of imperfections in plastic mouldings, the Ministry of Supply Chemical Inspectorate showed a system in which two capacitors are formed which have the moulding as dielectric. Each of these capacitors constitutes one element of a pair of a.c. potential dividers supplied with voltages in quadrature. The signals across the fixed arms of the dividers are amplified and after subjection to phase sensitive rectification are compared in a voltmeter circuit. Small defects such as voids in the moulding unbalance the circuits and show a signal on the voltmeter.

Radiographic study of metals in industry using a fluorescent screen is severely restricted because of the low intensity of the visual image and dark conditions are necessary for viewing. In medical radiography dark conditions are also required for fluoroscopy because of the need to use low intensity X-rays. This difficulty is largely overcome by the X-ray image intensifier tubes shown by the Phillips Electrical Ltd. The tube is a form of image convertor and has at one end a fluorescent screen on which the X-ray image is formed and which is backed by a photo-cathode. The electron emission image so produced is intensified by suitable accelerating electrodes and focused on a fluorescent screen to give an optical image. With tubes now available, a brightness gain of over 1000 can be obtained, which allows steel up to $\frac{3}{8}$ in. thick to be examined by fluoroscopy in the dim daylight. A demonstration showing an X-ray picture of the interior of a watch mechanism showed the remarkable intensity and contrast which these tubes can give.

Among their many optical and electrical inspection devices, Taylor, Taylor and Hobson Ltd. showed a turbine blade microscope by which the shape of the leading and trailing edges on a turbine blade can be viewed in full daylight at a magnification of ×40. Any part of the blade to within $\frac{1}{8}$ in. of the root can be viewed. A narrow band of light is passed obliquely around the edge of the blade to delineate the section, and this is viewed obliquely through the microscope. The image seen is that of the normal cross-section of the blade.

Elliot Brothers (London) Ltd. showed an interesting plating thickness tester developed by the British Non Ferrous Metals Research Association. A heated probe is pressed on to the plated surface, and this sets up a thermo-electric e.m.f. at the interface of the base metal and the plating in a region just below the probe. The e.m.f. causes a current flow and potential distribution on the surface of the plate, which is characteristic of the plating thickness and physical constants of the plate and base. The potential generated between a point in the probe and one a short distance away is a measure of the coating thickness and a calibration can be prepared for a particular probe temperature and coating and ba material.

Thickness gauges. A beta gauge for thickness measu ment of plastics, paper and thin metal foils was shown Isotope Developments Ltd. It included facilities for adju ment of weight or thickness settings to be made remote while still retaining the advantage of the balanced chamb compensation system. They also showed a back scatteri gamma thickness gauge for plate and tube wall thickne determinations. Ekco Electronics Ltd. showed a radiati thickness gauge including automatic standardization a scanning and suitable for use with gamma or beta source Standardization is effected every 30 min by automatical withdrawing the head from above the material and th amplifier sensitivity, zero, source decay and contaminati are checked and any errors corrected by servo mechanism The auto scanning facility enables the material to be regular inspected at predetermined intervals across its width, the dw time at each scan position being preset by the operator. the material thickness deviates beyond predetermined limi or if any circuit fault occurs a fault indication is given an the equipment shuts down. An auto thickness control ser can also be fitted.

For determining the thickness or substance profile alo the width of a sheet of paper or similar material the Baldw Instrument Co. Ltd. showed a compact beta-ray gauge syste complete with recorder and drive mechanism called th transverse profile unit. A strip of paper for study is cut o from its reel and placed in the instrument. A mechanis draws the strip between a beta source and receiver gaugi system at a constant speed. The output of the receiver displayed on a circular chart recorder so producing a thickne profile.

For continuous thickness gauging of yarn and detection slubs, the Dawe Instruments Ltd. showed an instrume designed in conjunction with the Linen Industry Researc Association. A parallel beam of light is passed through tw apertures to two photocells forming a balanced system. standard yarn or system of equivalent light transmission fitted across one aperture, while the yarn under test pass over the other. Any unbalance of the system due to excessi thickness operates a quick-acting cutter so that the slub ca be removed.

Gas and liquid analysis. The Cambridge Instrument C Ltd. showed an instrument for measurement of the oxyge dissolved in boiler feed water. The feed water is mad conducting by the addition of salt and a voltage is applie between a silver electrode and a mercury electrode in th solution. The current passing is a measure of the oxyge content and the effects of impurities are eliminated by th use of a differential circuit. Elliott Brothers (London) Lt showed a thermal conductivity type carbon dioxide g analyser employing a bridge of resistance thermomet elements, but including several features to stabilize th calibration such as automatic control of the sample gas flo rate; stabilization of the gas temperature and humidity an stabilization of the bridge supply voltage.

Position location on machine tools. To assist in hig precision positioning of, say, a table on a machine too Ferranti Ltd. showed a device in which prismatic gratin consisting of glass strips carrying a line structure are supe imposed and a parallel light beam passed through them, s that their relative movement modulates the light transmitte ne long grating is attached to the moving table and two arrow light beams passed through it and through a stationary ating. Each beam is monitored by a photocell so that an itput pulse is obtained as each line is passed, and these are ounted to give the distance travelled. An accuracy of tting of 0·0001 in. is possible with a 5000 line per in. ating.

Vacuum coating. The progress made in vacuum coating chnique was shown by W. Edwards and Co. (London) Ltd. lant is now available for vacuum deposition of a seven-layer chroic mirror of alternatively low and high refractive index yers and having uniform spectral response over a mirror of to 7 in. diameter. A modulated beam photometer provides ecise optical thickness control of the layers. Also metallized aper for capacitors can be prepared in a roll coating plant ıpable of evaporating coatings on paper at speeds up to 0 ft/min.

SUNDRY DEVICES AND COMPONENTS

As a novel method of generating acoustic radiation, mention ust be made of the exhibit by D. M. Tombs of the Depart-ent of Electrical Engineering, Imperial College, London, in hich he showed that by suitable arrangement of needle ectrodes and screens to which high voltages are applied, a orona wind could be made to blow in either direction and nder the control of the potentials in the system. Thus by odulation of these electrode potentials quite audible sounds ould be produced.

Much attention is being given to semi-conductor devices, nd an intriguing demonstration by the General Electric o. Ltd.'s Research Laboratories showed how an enhanced eltier cooling effect can be obtained at the junction between ne *p*-type and *n*-type forms of semi-conducting bismuth lluride, so that there is considerable ice formation at the nction. A temperature depression of up to 37° C was aimed.

For the measurement of power frequency currents, where ne use of iron-cored current transformers would be incon-enient as in high voltage systems, the British Electrical and llied Industries Research Association demonstrated the use f the Faraday magneto-optical effect. The heavy current to e measured is passed through a solenoid with a glass dielectric ore, along the axis of which is passed a plane polarized light eam. The magnetic field set up by the primary current auses rotation of the plane of polarization, and this angle of otation can be measured by nulling it with another optical otation caused by a second coil and dielectric system placed the path of the light beam and fed with a controlled current. he null is determined by a polaroid analyser and photo-ultiplier cell, the output of which, after amplification, feeds ne current to the second coil, so producing the null condition. ig. 6 shows the arrangement of the system.

The Research Laboratories of the General Electric Co. td. showed dielectric amplifiers which make use of the ariation in permittivity of ceramics and single crystals of rroelectric materials such as barium titanate with changes the applied electric field. This non-linear characteristic nables modulator and amplifier circuits to be set up. The ermittivity of these materials is also affected by temperature, articularly at the Curie point, so that they can be used to etect overheating and operate alarms.

Among the various relays shown, Electro Methods Ltd. owed variable time delay relays in which the delay is controlled from 1/6 to 180 s by a pneumatic bellows and slow leak system. They also showed high sensitivity miniature relays operating on 10 μW.

The Croydon Precision Instrument Co. showed a motor-driven thermocouple switch for high-speed operation and with a remarkably low contact noise level of less than 1/5 μV.

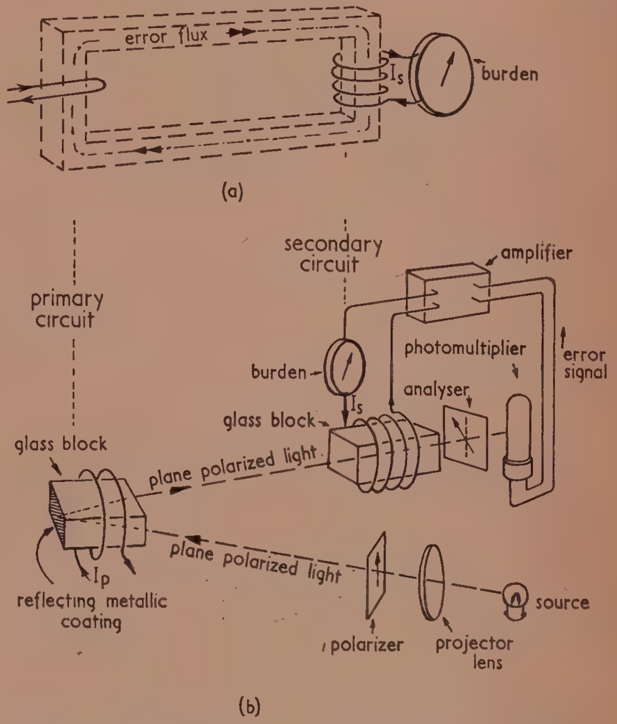


Fig. 6. The use of the Faraday magneto optical effect for current measurement

Interference filters displayed by Barr and Stroud Ltd. show that methods have been worked out for uniform deposition over large areas to produce dichroic filters up to 10 in. in diameter.

A moving magnet electrical indicating meter without a control spring was shown by the Royal Aircraft Establishment. It is based on the ratiometer principle in which a small high energy permanent magnet is constrained to rotate under the influence of two independent magnetic fields. One of these is supplied by a permanent magnet or by a current coil while the other is provided by a coil carrying the current to be measured. It can be arranged as a simple meter or as a ratiometer and gives an accuracy of $\pm 1\%$ full scale.

The availability of transistors is permitting the development of sub-miniature electronic amplifier assemblies and encouraging further miniaturization of other components. Fortiphone Ltd. showed a novel form of construction of sub-miniature audio transformers for hearing aids, in which the iron circuit consists of cup-shaped shells of single lamination thickness lapped together to an optical standard of flatness. Fig. 7 shows a cup type miniature transformer compared with a conventional design of equal ampere-turn/inductance characteristic. A miniature transistor oscillator high tension generator was also shown of size $\frac{1}{2} \times 1\frac{1}{8} \times 1\frac{3}{8}$ in. Other uses of transistors were displayed by Standard Telephones and Cables Ltd., including an intriguing demonstration of a telephone hand set which operated normally without any cord connexion between it and the subset. Germanium diode and triode transistors were employed. Germanium junction photocells were also shown in an apparatus for reading off data from punched tapes. The Research Laboratories of the General Electric Co. Ltd. showed a full wave rectifier bridge network using germanium *p–n* junction power diodes and used to feed a 1 kW heating element. Its remarkably small size is shown in Fig. 8.

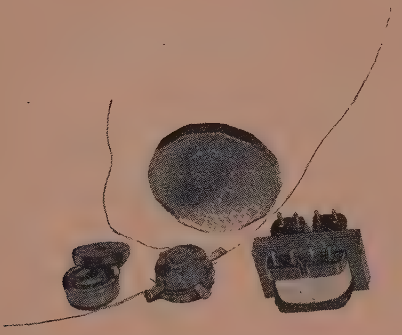


Fig. 7. Comparative size of the cup type transformers

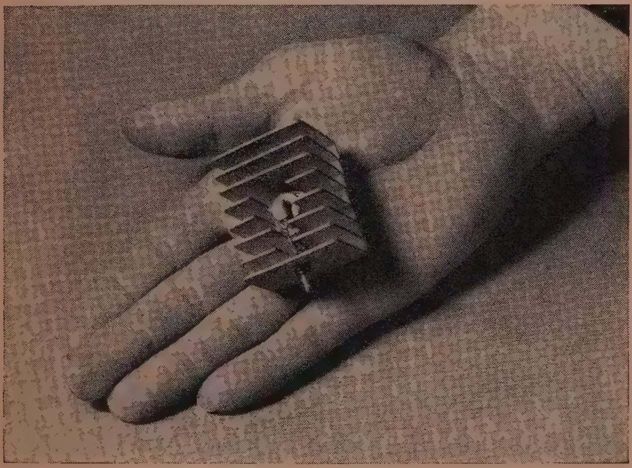


Fig. 8. Small size of the germanium *p–n* junction type power rectifier

A wide range of linear and graded potentiometers and lo friction types of interest to the servo engineer was shown b Salford Electrical Instruments Ltd.

Electrical resistance strain gauges consisting of thin meta foils mounted on an ethoxylene lacquer backing, and etche into any pattern of wire required, were shown by Saunders Roe Ltd. These elements have the advantage that th rectangular wire section so formed permits better hea dissipation to the surface on which it is mounted, and so hig currents can be used. These bridges can be used to driv directly quite robust meters and recording galvanometers.

Evershed and Vignoles Ltd. showed an impressive range c servo motor and servo amplifier units.

Several types of magnetic drum stores for computers wer exhibited. One by Plessey Co. Ltd. has a capacity c 100 000 bits in a surface medium of cobalt-rich cobalt nicke alloy. The tracks are arranged at 16 to the in. and in eac track the digit packing is 40 to the in. The pick-off signa amplitude is about 10 mV. The drum peripheral velocity i 900 in./s. Equipped with five input and output buffer storag units each of 16 decimal digits provides for punching c storing all eighty columns of a Hollerith card.

MATERIALS

Developments in the methods of preparation and fabricatio of tantalum, niobium and zirconium were shown by Mure Ltd. and Accles and Pollock Ltd. A wide range of tubes i these metals were shown, including capillary tubing, mult bore tubing, Bourdon tubing and composite tubing made wit differing metals inside and out. Quartz products were show by The Thermal Syndicate Ltd., including fused quart helical springs and tapered springs for micro-analytical wor and quartz wool with an average strand diameter of 6 μ Graded joints of fused quartz to borosilicate glass we shown. Glasses stabilized against the effects of radiatio were shown by Chance Brothers Ltd., including a heavy lea glass suitable for a radiation shield and stabilized wit cerium oxide. They also showed a new blue glass with goo heat-absorbing qualities, and suitable for steel melter goggles, which was developed in conjunction with the Britis Iron and Steel Research Association and the Nationa Physical Laboratory.

The usual excellent range of precious metal products we displayed by Johnson, Matthey and Co. Ltd. Wax protecte precision silvered mica capacitors were also shown in th range 5 pF to 0·25 μF and with tolerances of ±0·5% c ±1 pF.

Craftsmanship and Draughtsmanship Competition

EXTRACT FROM JUDGES' REPORT

There was again an increase in the number of entries for this competition, there being 130 this year, compared with 129 for 1954 and 112 for 1953. The Judges are glad to see that the interest is so steadily maintained. The general standard in the Junior section of the Scientific instruments and components class was not quite up to that of previous years and only two prizes were awarded. In the Senior section, however, the standard was more satisfactory.

In the Tools and gauges class there was a more consistent entry than in previous years, partly because the entries were limited to tools and gauges required for constructions of scientific instruments and apparatus, thus eliminating heavier engineering production tools, and partly due to fewer entri of an elementary kind which do not give scope for showin skill needed to warrant a prize.

There were only four entries in the Optical componen and systems class, but two of these were of exception quality, and two prizes are therefore recommended.

Both the number of entries and the standard of work su mitted for the Blown-glass and silica ware class continue t give satisfaction. There was a much greater representatio this year in the Functional models of scientific interest cla and the work was of good standard. There was again a ve satisfactory entry in the Draughtsmanship class. There w a marked improvement in the standard of the Senior entrie

Some entries of instrument joinery were sent in, but could not be accepted as there is not a class covering this work. It may be worth considering whether to set up a class for work of this nature, as applied in the instrument industry.

PRIZE LIST

Scientific instruments and components (Junior grade)

First prize: A. R. BANNING (Northampton Polytechnic). Edgewise indicating pressurestat mechanism.

Second prize: D. J. JAMES (Joseph Barrett Youth Centre). Air-operated controller mechanism.

Honourable mention: K. J. RICKATSON (George Kent Ltd.). Planimeter.

Scientific instruments and components (Senior grade)

First prize: H. R. PHIPPS (Hilger and Watts Ltd.). Fixed symmetrical slit twin aperture.

Second prize: J. K. BATCHFORD (Marconi's Wireless Telegraph Co. Ltd.). Relay for recorder.

Third prize: M. L. BARNETT (Department of Engineering, National Institute for Research in Dairying). Pitchometer.

Honourable mention: J. R. MORRIS (Hilger and Watts Ltd.). Micrometer head for micrometer water level.

Tools and gauges (Junior grade)

First prize: J. C. DONNEX (Services Electronics Research Laboratory). Circular table (6 in.).

Second prize: A. S. IVES (Services Electronics Research Laboratory). Gernor sine bar.

Third prize: D. G. PINNOCK (Services Electronics Research Laboratory). Blade bevel protractor (6 in. and 12 in.).

Honourable mention: R. D. SMITH (Standard Telephones and Cables Ltd.). Swivel angle plate with sine bar adjustment.

Honourable mention: R. G. GAMMON (Atomic Weapons Research Establishment). Sine centres (10 in.).

Tools and gauges (Senior grade)

First prize: B. BYGRAVE (Services Electronics Research Laboratory). Vertical mechanical comparator.

Second prize: J. C. HOLTON (Standard Telephones and Cables Ltd.). Compound slide for watchmakers' lathe.

Third prize: R. CORFIELD (County Technical College, Stafford). Compound sine table.

Honourable mention: R. J. LOWE (Standard Telephones and Cables Ltd.). Vertical slide lathe attachment for milling.

Optical components

First prize: I. A. PHILLIPS (Hilger and Watts Ltd.). Quartz Cornu prism.

Second prize: M. L. HAMMOND (National Physical Laboratory). Lummer Brodhum photometric cube.

Blown-glass and silica ware

First prize: A. H. MOORE (Mullard Radio Valve Co. Ltd.). Ball condenser.

Second prize: A. J. OSBORNE (Research Laboratories, General Electric Co. Ltd.). Ether condenser.

Third prize: S. F. TILFORD (Mullard Radio Valve Co. Ltd.). Ball type condenser.

Honourable mention: D. J. KEAST (British Thomson-Houston Co.). Micro hydrogen generator.

Honourable mention: K. R. WOLFE (British Thomson-Houston Co.). Ammonia distillation apparatus.

Sections of instruments, functional scale models of scientific interest and patterns

First prize: K. S. ROSS (Standard Telephones and Cables Ltd.). Scale model, pantograph engraving machine.

Second prize: G. COLLINGS [Elliott Bros. (London) Ltd.]. Servo unit (oil).

Third prize: G. P. GIBBS-MURRAY [Elliott Bros. (London) Ltd.]. Integrator.

Honourable mention: M. A. SPITTLES (George Kent Ltd.). Half scale (½ size) venturi meter.

Draughtmanship (Junior grade)

First prize: J. M. JAY (British Thomson-Houston Co.). Wire-draw bench (110 ft).

Second prize: R. A. WOLFE (British Thomson-Houston Co.). Selsyn transmitter unit for precision recording instruments.

Third prize: D. T. COX (British Thomson-Houston Co.). Transformer tapping switch.

Honourable mention: D. E. TURNER (Electric and Musical Industries Ltd.). Drive unit.

Draughtsmanship (Senior grade)

First prize: J. P. SIMMS (Electric and Musical Industries Ltd.). Correction gear box.

Second prize: T. M. LAWMON (Electric and Musical Industries Ltd.). Drive unit.

Third prize: W. J. ARNOLD (Electric and Musical Industries Ltd.). Gear box and contact assembly.

Third prize: K. A. BATTLE (Electric and Musical Industries Ltd.). Gear box and contact assembly.

Silvanus P. Thompson Prize

Prize winner: G. P. GIBBS-MURRAY [Elliott Bros. (London) Ltd.]. Integrator (drawing). Integrator (instrument).

Honourable mention: C. J. BROWN [Elliott Bros. (London) Ltd.]. Six-colour recorder (drawing). Ribbon mechanism (instrument).

ORIGINAL CONTRIBUTIONS

A spectrometer for single crystal neutron diffraction

By G. E. Bacon, M.A., Ph.D., F.Inst.P., and R. F. Dyer, Atomic Energy Research Establishment, Harwell, Berks

[*Paper received* 6 *April*, 1955]

A description is given of an instrument for neutron crystallography, specially designed for measurements with single crystals. The small size is in marked contrast with that of the conventional spectrometers designed for powder diffraction methods.

One of the most noteworthy features of the neutron spectrometers previously used(1–3) for the measurement of diffracted beams has been their large size compared with the corresponding apparatus for X-ray diffraction. This has been a result of the fact that they have been designed for the use of powder diffraction methods, employing the large samples and large counters which are then necessary because of the relative weakness of neutron beams. To obtain adequate resolution from these large samples, bearing in mind the fact that the diffraction haloes remain stationary in angular position and intensity irrespective of any rotation of the sample, it is necessary to set the counter aperture at a distance of two feet or more from the axis of the instrument. Moreover, such a counter is usually about two feet long and when surrounded by several inches of shielding material, to ensure a low background intensity, becomes very heavy: thus a very substantial form of instrument construction is necessary in order to give the required rigidity and angular precision.

When the diffraction by single crystals is being examined the construction becomes simpler. Not only may the samples be very much smaller, even although a smaller and less efficient counter is used, but also the problem of obtaining adequate resolution disappears. A diffracted beam is produced only when the crystal (and with it the counter) passes through a narrow angular range determined by the incident collimation and it becomes possible to set the counter aperture, which may measure an inch or more, within a few inches of the crystal. We have taken advantage of these considerations in the design of the instrument shown in Fig. 1. In principle it is possible to make the instrument still smaller by using some type of scintillating crystal(4,5) as detector. However, as developed so far the latter are rather too sensitive to the γ-ray background for satisfactory use as thermal neutron detectors and we have relied on a development of the normal boron trifluoride proportional counter.

The monochromating crystal, which selects a narrow band of wavelengths from the spectrum of neutrons produced in the nuclear pile, is situated about 10 in. within the pile shield, so that from the rectangular aperture *A* in Fig. 1 emerges a beam of monochromatic neutrons with a wavelength centred on 0·80 or 1·09 Å according to whether a copper or lead single crystal is used as the monochromator. The diffracting sample which is being examined, in the form of a single crystal, is mounted on a set of standard Unicam X-ray goniometer arcs *B* which are carried by the spindle *C* on the axis of the instrument.

The detecting counter, which is at the centre of the shield *D* of boron carbide and paraffin wax, is 6 in. in length and 1 in. in diameter and is filled to a pressure of 70 cm of mercury with boron trifluoride gas made from the boron 10 isotope. It is carried on the machined plate *E* by four ball-race wheels *F* and is rotated around the axis of the instrument by a reversible motor which drives through a pinion engaging o the peripheral rack *G*. The gearing is such that the counte arm rotates at about 7 degrees/h, the slow speed bein essential in order that the weaker diffracted beams shall n be significantly impaired by random fluctuations of th background intensity.

A train of four precision spur gear wheels, two of whic can be seen at *H*, drive the specimen spindle *C* at half th angular velocity of the counter arm, thus ensuring that particular set of reflecting planes shall remain in the reflectin position as the successive orders of reflexion are tracke through by the counter. The counter output is fed *via* a amplifier and ratemeter to a pen recorder, on the chart c which calibration marks indicating angular displacemen are superimposed by a microswitch *I*. The direction c rotation of the counter arm is reversed at the ends of i travel by microswitches, one of which can be seen at *J*, thu making the operation of the instrument automatic and pe mitting a number of successive records of a series of reflexion to be obtained.

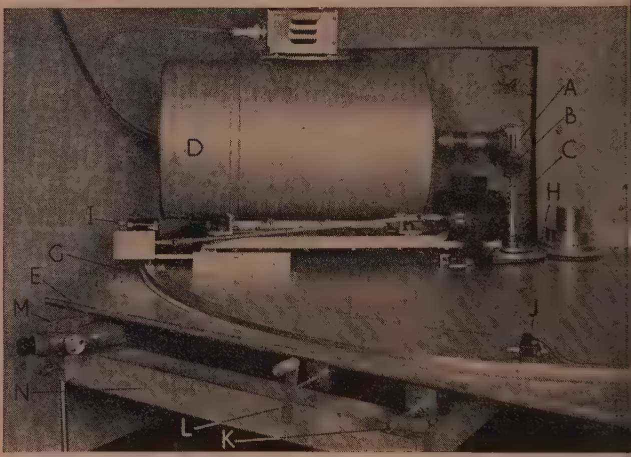


Fig. 1. General view of instrument mounted on pile face

In order that the specimen crystal may be rotated independently of the counter arm, when a new reflexion plane being alined, a spring-loaded clutch which disengages th gear train is provided and is operated by the lever *K*: th crystal can then be rotated by the handle *L*. A scale an vernier, fitted to the bottom of the spindle *C*, is read b means of the telescope *M* to give the angular position of th crystal to within one minute of arc. The supporting framework *N* which carries the whole assembly can be remove easily from the pile face when necessary.

The construction of the instrument is such that there is a acklash of not more than three minutes of arc between the ounter and crystal positions: this is acceptable experientally. A typical record obtained is illustrated in Fig. 2 hich shows the reflexions from the (h00) planes of a single ystal of potassium hydrogen bisphenylacetate: the peak tensities are about 50% of those obtained with the large ectrometer described(3) previously. A determination of the -ordinates and contours of scattering density for the ydrogen atoms in this compound is serving as the first test the new instrument.

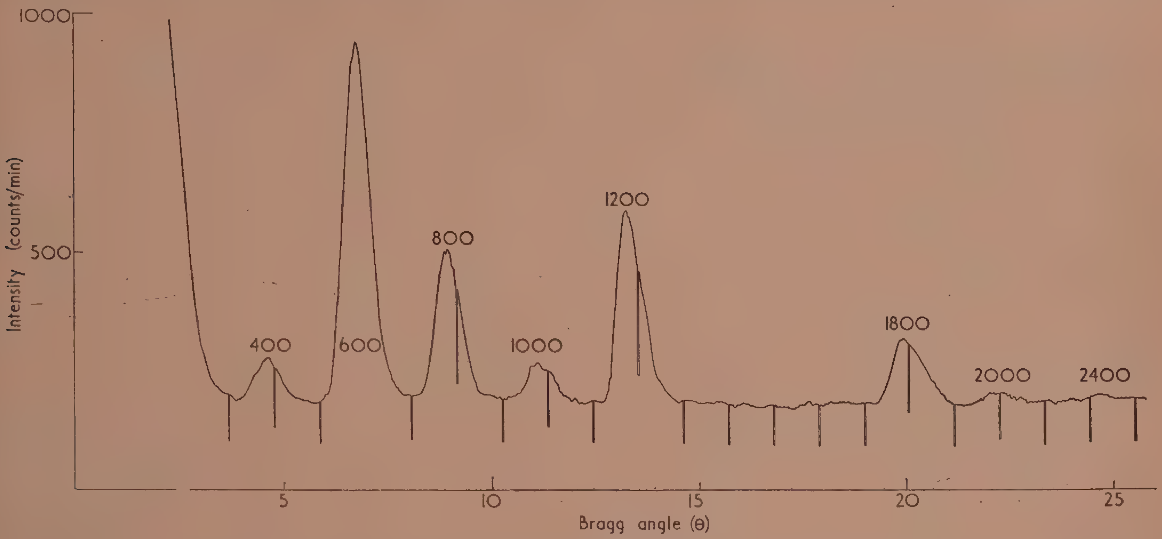


Fig. 2. Recording of (h00) reflexions from potassium hydrogen bisphenylacetate, with angular calibration marks superimposed

REFERENCES

(1) WOLLAN, E. O., and SHULL, C. G. *Phys. Rev.*, **73**, p. 830 (1948).
(2) HURST, D. G., PRESSESKY, A. J., and TUNNICLIFFE, P. R. *Rev. Sci. Instrum.*, **21**, p. 705 (1950).
(3) BACON, G. E., SMITH, J. A. G., and WHITEHEAD, C. D. *J. Sci. Instrum.*, **27**, p. 330 (1950).
(4) BERNSTEIN, W., and SCHARDT, A. W. *Phys. Rev.*, **85**, p. 919 (1952).
(5) SCHENCK, J., and HEATH, R. L. *Phys. Rev.*, **85**, p. 923 (1952).

A simple 500 Mc/s oscillator for use with electrodeless mercury-198 lamps

By A. THULIN, Bureau International des Poids et Mesures, Sèvres, France

[*Paper received* 18 *January*, 1955]

The oscillator, simply adjustable in frequency from 300 to 500 Mc/s, consists of a parallel line resonator associated with a double triode developed for mobile transmitters. It is intended for the excitation of electrodeless mercury-198 lamps for use in interferometry.

ectrodeless mercury-198 discharge tubes, as used for interrometry purposes, have a restricted life owing to the clean-up mercury, although it is possible to regenerate the tubes veral times by heating them in a flame. The clean-up minishes rapidly with increasing frequency of excitation,(1) hich should then be as high as practicable. Some authors(2) en use radar frequencies.

Appreciable clean-up in a mercury-198 tube that had been frequent use for several years was observed—and it was ought necessary to replace a 100 Mc/s oscillator by one ving higher frequency and efficiency. In order to avoid e use of expensive and specially designed magnetron cuits, the author chose a parallel line resonator using a uble-tetrode developed for mobile transmitters, type QE 06/40 (by Philips Electrical Ltd.).(3) As the discharge be has a high impedance it was believed that the best efficiency would be obtained by placing this close to the input of the resonator where the electric field strength has its maximum. This avoids the use of matching circuits as is necessary if transmission line coupling is used. Due to the high frequency the oscillator itself can have quite reduced dimensions, the necessary voltages being obtained from a separate power supply.

The circuit diagram of the oscillator is given in Fig. 1 and of its power supply on Fig. 2. The actual lay-out is shown in Fig. 3. The oscillator tube and resonator are mounted horizontally on a wooden support *A*. The tube holder is mounted on a vertical Duralumin plate *B* which is also provided with two lead-through insulators *C* for the grid coupling connexions. The $\lambda/4$ resonant line is made up of two copper tubes *L* having a diameter of 12 mm and a spacing between centres of 45 mm. The tubes are mounted by means of the ring holders *K* on standard 76 mm insulating columns *J*. The length of the tubes, 250 mm, was chosen so that the frequency could be adjusted from 300 to 500 Mc/s by simply sliding the short-circuiting bar *M*. The connexion of the copper tubes to the anodes of the resonator is made by using thin flexible copper bands *E*. The coupling condensers *C* are each made up of two copper bands *D*, 1 mm thick and 12 mm in width, parallel to each other and with a spacing of approximately 4 mm. The bands are fixed rigidly, one on the resonator tube and the other on the corresponding lead-through insulator so as to form a condenser length of about 40 mm. All the high frequency chokes are air wound with a core diameter of 8 mm using 1 mm enamelled wire and spacing of approximately 2 mm. The length of these co should be at least 50 mm. Dimensions of coils and condense are generally not critical.

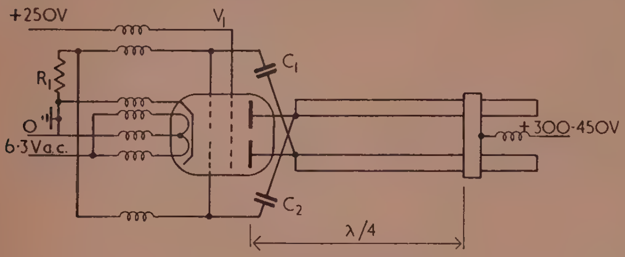


Fig. 1. Oscillator circuit

$R_1 = 20$ kΩ, 2 W
C_1, C_2 = see text
V_1 = Philips QQE 06/40

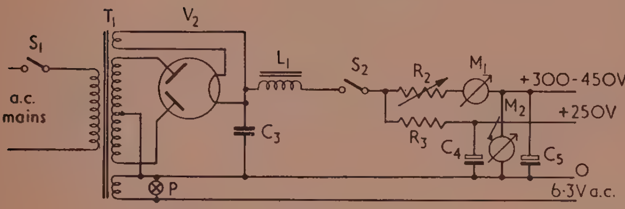


Fig. 2. Power supply circuit

$R_2 = 11 \times 250$ Ω, 15 W variable with selector switch
$R_3 = 11$ kΩ, 15 W
$C_3 = 2$ μF, 1000 V working
C_4, C_5 = 32 μF, 500 V working
$L_1 = 13$ H, 200 mA
T_1 = mains transformer, secondary: 2 × 500 V, 200 mA; 5 V, 3 A; 6·3 V, 3 A
M_1 = 0–250 mA milliameter
M_2 = 0–500 V voltmeter
S_1 = mains switch
S_2 = 500 V single-pole switch
P = 6·3 V pilot lamp
V_2 = 5Z3

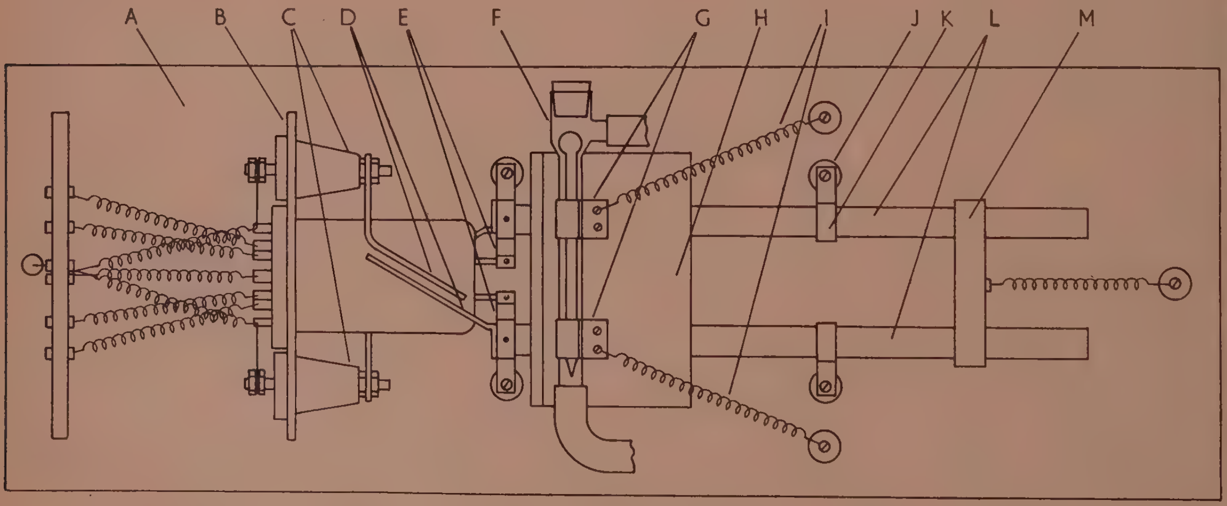


Fig. 3. Plan view of the lay-out of the oscillator

The discharge tube in its water cooling-jacket is mount on a Perspex bridge *H* near to the anode output leads. available, a better material than Perspex could be used avoid high frequency absorption effects. The glass coolin jacket *F* is kept in place by the two open rings *G* made fro thin copper plate. A high tension spark on the surface the cooling-jacket is necessary for starting the mercury-1 lamp. This is obtained by applying the output of a Tes coil to the open rings. To avoid power absorption two lo chokes *I* are used for this connexion. The Perspex insulati should be such as to prevent any sparkover to the oscillat circuits. If high frequency radiation is undesirable, t oscillator unit could be placed in a metal-screen box, b care should be taken so as to avoid this having any of dimensions equal to $\lambda/2$.

As with all power handling tubes it is preferable to allo for some warm-up time before switching on the high tensi to the oscillator tube. This is made manually using t switch S_2 in the power supply, but could of course be ma automatically by using a thermal switch. The high frequen power output is approximately 60 W and is made adjustab by means of the variable resistor R_2. The amount of dire current power fed to the oscillator can be obtained by mul plying the readings of the meters M_1 and M_2. According the manufacturer, the efficiency of the oscillator tube is bett than 66% up to 500 Mc/s. The use of higher frequenci should be avoided to prevent excessive heating of the tub Generally, little power is necessary for good intensity of t lamps and the total power absorption of the water circuit only a few watts.

The apparatus described has been in use for more than year, giving very satisfactory results.

REFERENCES

(1) Meggers, W. F., and Westfall, F. O. *J. Res. Nat. B Stand.*, **44**, p. 451 (1950).
(2) Jacobsen, E., and Harrison, G. R. *J. Opt. Soc. Ame* **39**, p. 1054 (1949).
(3) Dorgelo, E. G., and Zijlstra, P. *Rev. Tech. Phili* **12**, p. 166 (1950).

The characteristics of photomultiplier tubes and their use for absorption measurements

By K. W. Keohane, B.Sc., and W. K. Metcalf, M.B., B.S., Department of Anatomy, University of Bristol

[*Paper received* 23 *December*, 1954]

Estimates have been made of the uniformity of the spatial characteristics of type 1P21 photomultiplier tubes and their variation with wavelength. It has been found that these tubes have remarkably uniform characteristics (of the order of 0·5%) and that the area of maximum sensitivity of the photocathode can be repeatedly located to a similar order of accuracy. It is suggested that the errors demonstrated by Edels and Gambling⁽¹⁾ are due to their experimental method rather than a true representation of the spatial characteristics of the photocathode. Linearity of the photomultiplier input/output characteristics has been measured for the range 2 — 0·05 μA and no departures from linearity can be detected within the experimental accuracy (0·5%).

efore the suitability of photomultiplier tubes for the measure-ent of low intensity light signals can be assessed, it is ecessary to ascertain how far the following criteria are tisfied.

(i) The input-output characteristics should be linear at each wavelength over the range which is to be used in the experiment.

(ii) The photocathode should be uniform over at least a part of its surface, otherwise comparisons can only be made between results if the optical line-up is sufficiently exact to ensure that the same area of cathode is used in each experiment.

r (iii) the spatial variations in sensitivity should be the same for all wavelengths.

(iv) The tubes should not be subject to fatigue effects at the current output levels used in the experiments.

It has been suggested that as none of these criteria holds xactly, an accuracy of the order of 1% can only be obtained one photomultiplier is used with precise optical alignment. xperimental conditions exist for which this is true, and it as been shown that there are limits to the linearity of these ibes and that fatigue effects can be considerable. However, gnal strengths at which these factors become significant an be avoided.

We have been interested in microspectrophotometry as a ethod of quantitative cytochemistry. To improve on the % accuracy obtainable using photographic methods, a hotoelectric technique has been employed, in which type P21 photomultiplier tubes are used. A block diagram of e method is shown in Fig. 1.

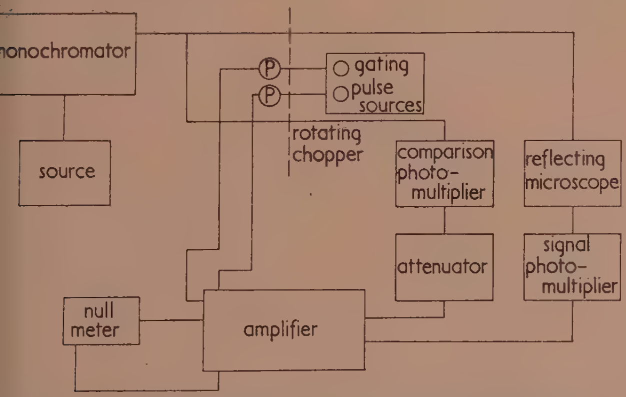


Fig. 1. Block diagram of microspectrophotometer incorporating a Burch type reflecting microscope

To obtain a balance, the electrical attenuator (a calibrated, continuously-variable logarithmic device) is adjusted until the output from the comparison photomultiplier is equal to that from the signal photomultiplier as observed on a null reading output meter. The effect of fluctuations in the source intensity are thus eliminated. A more complete account of this apparatus is being prepared for publication.

The monochromator used was a Littrow type double transmission instrument in which spectral impurity due to scatter had been reduced. The experiments were designed to test whether it was possible to use a two tube method to compensate for source fluctuations in our microspectrophotometric apparatus. Signal strengths used were below those which we had previously found to cause fatigue. Possible errors were thus reduced to the non-uniformity of spatial variations at different wavelengths and to non-linearity of the photomultipliers.

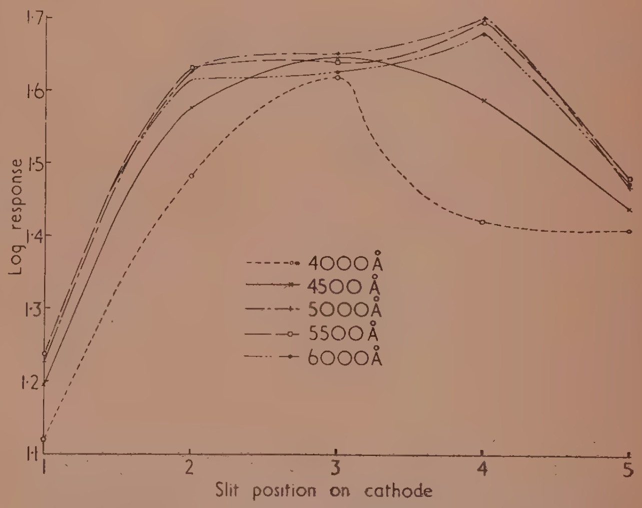


Fig. 2. Graph showing the response across a type 1P21 photomultiplier cathode at different wavelengths; obtained by moving the slit

In the experiments of Edels and Gambling⁽¹⁾ the characteristics of type RCA 931A tubes were obtained by measuring their output at various positions of a slit moved in front of the illuminated photocathode. The results they obtained showed a marked non-uniformity in spatial characteristics, the form of which varied considerably with wavelength. We feel that their technique is not permissible. It is exceedingly difficult, even after careful optical mixing, to obtain a patch of light sufficiently uniform in both intensity and spatial distribution to permit such a procedure. Repeating the experiments of Edels and Gambling we obtained results which closely resemble those that they publish (Fig. 2). The experiments were then modified. Non-uniform illumination was avoided by keeping the slit fixed in relation to the patch of light and the photomultiplier moved in a horizontal plane above it.

Fig. 3 shows the curves obtained when photomultiplier output was plotted against photocathode position at each wavelength.

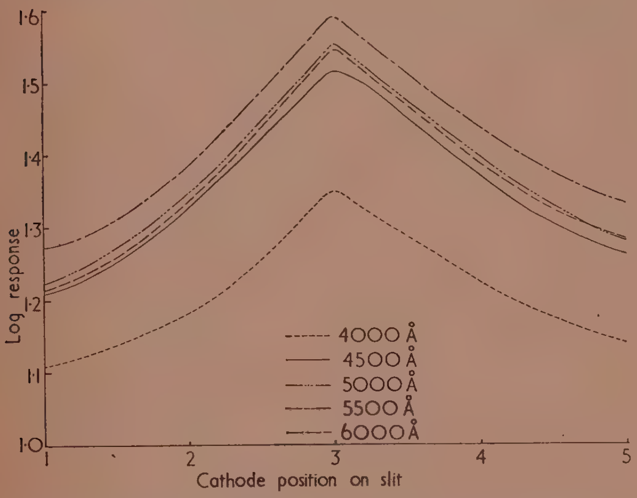


Fig. 3. Graph showing the response across a type 1P21 photomultiplier cathode at different wavelengths; obtained by moving the cathode

We put

$I_{0\lambda}$ = output from the signal photomultiplier in the zero position of the cathode at wavelength λ;

$I_{c\lambda}$ = output from the comparison photomultiplier at wavelength λ;

$a_{0\lambda}$ = attenuator reading necessary to make the output from the comparison beam equal to that of the signal beam when the signal tube is in the zero position at wavelength λ.

Similarly $I_{1\lambda}$, $a_{1\lambda}$, etc., are values of signal photomultiplier output, attenuator reading, etc., corresponding to the photomultiplier at a position 1 off centre.

$$\begin{aligned} I_{0\lambda 1} &= a_{0\lambda 1} \cdot I_{c\lambda 1} & \qquad I_{0\lambda 2} &= a_{0\lambda 2} \cdot I_{c\lambda 2} \\ I_{1\lambda 1} &= a_{1\lambda 1} \cdot I_{c\lambda 1}, \text{ etc.} & \qquad I_{1\lambda 2} &= a_{0\lambda 2} \cdot I_{c\lambda 2}, \text{ etc.} \qquad (1) \end{aligned}$$

In order that characteristics shall be uniform with wavelength.

$$I_{0\lambda 1}/I_{1\lambda 1} = I_{0\lambda 2}/I_{1\lambda 2} \quad \text{i.e.} \quad a_{0\lambda 1}/a_{1\lambda 1} = a_{0\lambda 2}/a_{1\lambda 2} \qquad (2)$$

From which

$$\log a_{0\lambda 1} - \log a_{1\lambda 1} = \log a_{0\lambda 2} - \log a_{1\lambda 2} \qquad (3)$$

The table shows typical results obtained for two positions of the photomultiplier illuminated with light of extremes in wavelength for two different monochromator resolutions.

The error in changing from 6000–4000 Å for a movement of the order of 2 mm from the centre of the photocathode is only about 0·2% for wide slit widths or 0·4% for narrow slits. These errors are of the same order as the repeatability of the readings with our apparatus.

Table showing typical results obtained for two positions of t photomultiplier at 6000 and 4000 Å for two different mon chromator resolutions

Slit width (mm)	*Wave-length (Å)*	*Log output at central position (log a_0)*	*Log output 2 mm off centre (log a_1)*	*Log a_0 − log a_1*	*Antilog.*	*Erro (%)*
1·5	6000	1·545	1·665	0·120	1·318	0·2
	4000	1·414	1·535	0·121	1·321	
0·5	6000	1·587	1·663	0·076	1·186	0·4
	4000	1·486	1·560	0·074	1·191	

An estimate was made of the accuracy with which the photomultiplier could be positioned for maximum sign output. It was found that this was within the experiment error (of the order of 0·5%) at all wavelengths fro 4000–7000 Å.

LINEARITY OF COMMERCIAL PHOTOMULTIPLIER TUBES

Kortum and Maier$^{(2)}$ have recently published an estima of the non-linearity of commercial photomultipliers whic they say may be as much as 10%. In view of their result we decided to investigate the input-output characteristics type 1P21 tubes in the current ranges that we generally u (0–2 μA). Two sets of experiments were performed. Eac consisted in principle of keeping the comparison sign constant whilst the signal beam intensity was measured wit and without a fixed attenuation in the optical path to t signal photomultiplier. This was repeated at various leve of illumination.

Let I_s = output from signal photomultiplier.
I_c = output from the comparison photomultiplier.
a_0 = attenuator reading.

$$I_s = a_0 I_c \qquad ($$

When optical attenuation is placed in the beam I_s becom I'_s

$$I'_s = a'_0 I_c \text{ and hence } I_s/I'_s = a_0/a'_0 \qquad ($$

From which $\quad \log I_s/I'_s = \log a_0 - \log a'_0 \qquad ($

Log I_s/I'_s is effectively a value of the log of the attenuatio of the signal beam introduced by the optical filter. T second series were a slight variant, attenuation being obtaine by varying the aperture diaphragm of the signal beam. T linearity of the photomultipliers, for signal strengths rare exceeding 2 μA and falling to approximately 0·05 μA certainly of the same order as the accuracy of our techniqu which, as has been stated previously, is reproducible to 0·5%

ACKNOWLEDGEMENTS

Our thanks are due to Professor J. M. Yoffey in who laboratories this work was conducted, and for the gran obtained through him from the Rockefeller Foundation a the Medical Research Council.

REFERENCES

(1) Edels, A., and Gambling, W. A. *J. Sci. Instrum.*, 3 p. 121 (1954).
(2) Kortum, G., and Maier, H. *Naturforsuch*, 8a, p. 2 (1953).

field instrument for measuring temperatures of natural boiling pools

By Z. S. Garvitch, Dominion Physical Laboratory, Department of Scientific and Industrial Research, Lower Hutt,
New Zealand

[*Paper received* 7 *February*, 1955]

A prototype instrument is described by which the temperature of natural boiling pools may be compared with the local boiling point of pure water. The difference in temperature is indicated by a meter on which changes of 0·02° C are easily detectable. The power required is provided by a motor-cycle battery, and the whole instrument is mounted on a pack frame. A proposal for an improved lighter model of the instrument is included. The equipment may also have a use as an alpine height-finder.

or measuring the temperature of natural boiling pools in e Taupo–Rotorua thermal area of New Zealand it has een found convenient to use an instrument capable of rect measurement of superheat, since unless this is done, oublesome measurements of barometric pressures must be ade. In the instrument described here, one sensitive element a differential resistance-thermometer bridge is immersed the pool, and the other sensitive element is located per- anently inside a miniature hypsometer built into the instru- ent. The indication on the instrument meter is therefore a easure of the difference between the temperature of the ool and the local boiling point.

By arranging for the sensitive element inside the hypsometer be replaced by a fixed manganin resistor, the instrument n also be used as a conventional resistance thermometer. he whole instrument, including the hypsometer with motor- ycle batteries to heat the water, and the temperature measur- g equipment, is mounted on a pack-frame.

The indicating meter is rugged, and its superheat scale overs the range −1 to +4° C (superheat) (i.e. 1° C below oiling point to 4° C above boiling point), divided in tenths a degree. The resistance-thermometer temperature scale overs the range 20 to 120° C, with two-degree divisions.

The design of the hypsometer and that of the temperature- easuring circuits are described separately below.

THE HYPSOMETER

The proportions of the hypsometer were governed by two ctors. It was necessary to have a steam-filled enclosure ng enough to admit the temperature-measuring probe for libration. It was desirable also to have the hypsometer ng and narrow to reduce the likelihood of spilling the water hile the instrument was being carried. Hypsometers of esigns and proportions different from the one described ere, including one after a sketch by Koppl,* were made and sted, but the present design offered the greatest length of iform temperature within the hypsometer.

The hypsometer (Fig. 1) is a cylinder $4\frac{1}{2}$ in. long by $1\frac{1}{4}$ in. ternal diameter. It is divided internally into two sections a thin annular disk *A*. The lower section contains about cm^3 of water which is kept boiling by an electric element, d the upper section forms a steam-filled enclosure. The eam is directed up a tube *B*, which is fixed into the centre the disk, and down the surrounding annular space to e outlet *C* situated at the bottom of the upper section. eam then passes up the outlet tube *D* and thence to a mple condenser. Condensed vapour returns down the wer tube to the bottom chamber. The hypsometer is led with water through an opening in the top. The proper level is obtained by an overflow *E* which is closed off after filling.

The fine mesh grill *F* prevents splashes of water reaching the sensitive element *G* permanently installed in the central steam-filled chamber.

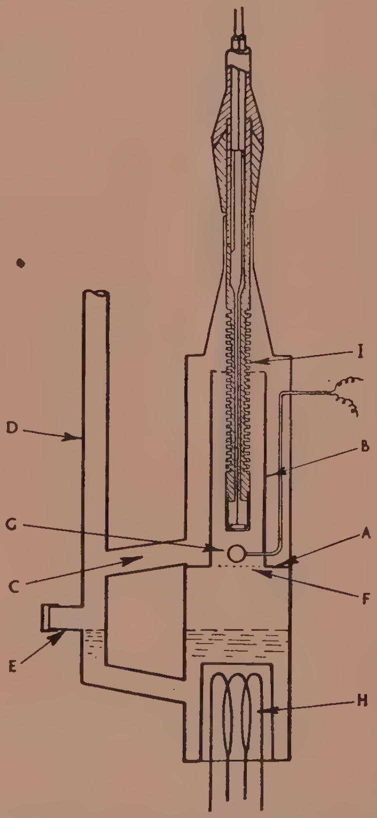


Fig. 1. Schematic diagram of hypsometer and temperature sensitive probe

The hypsometer is lagged with cork and fitted into an insulated compartment under the instrument panel. The filling and calibration entry protrudes through the panel, and the overflow outlet comes out the side of the instrument case.

Heating circuit. The water is heated by an immersed element wound with Nichrome tape. Power is supplied by two 6 V motor-cycle batteries—one working and one spare—housed in a box below the instrument. Leads are also provided so that an external battery of higher voltage can be employed to speed up the initial heating if desired.

---

* Koppl, F. *Rev. Sci. Instrum.*, **18**, p. 850 (1947).

The heater consists of three separate elements of different wattages which are switched independently to provide a maximum of 30 W at 6 V. By means of the switches, the wattage can be adjusted so that the water is kept just boiling. The elements are fitted into a flat metal envelope which is soldered into a slot in the bottom cap of the hypsometer (*H*, Fig. 1). With all the elements in parallel (30 W at 6 V) the hypsometer takes approximately 20 min to boil, so that in practice it is usual with this model to pre-heat the water with an external 12 V battery, and then use the 6 V battery to maintain the temperature. Approximately 16 W are necessary to keep it boiling.

In addition to the three heater switches, there is an external master switch mounted in a position accessible to the operator while the pack is being worn. This enables him to move about with the instrument at the "ready," and to have the hypsometer boiling when it is required.

THE TEMPERATURE MEASURING CIRCUITS

Thermistors were chosen for the temperature sensitive element of the equipment. They are a flat disk type measuring 0·2 in. diameter and 0·03 in. thick, the resistances of which change from 600 Ω at 20° C to 68 Ω at 100° C. The measuring circuit is in the form of a Wheatstone bridge. Its three ranges—selected by a range switch (S_1, Fig. 2)—are marked "superheat," "temperature" and "calibration." The indicator is a 0–100 microammeter, the zero of which has been set up $\frac{1}{5}$ of full scale. Zero coincides with 0° C on the superheat scale. Common to all three ranges are two 70-Ω ratio arms (R_1 and R_2) and the temperature sensitive probe (Th_1).

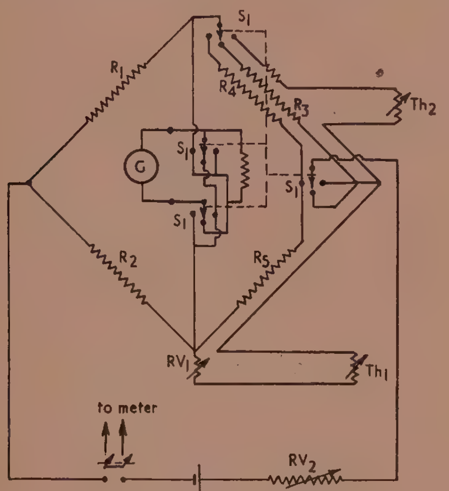


Fig. 2. Temperature measuring circuit

R_1, R_2 = 70 Ω w.w. manganin

R_3 = 1000 Ω approximately (adjusted for correct temperature range) w.w. manganin

R_4 = 65 Ω approximately (adjusted for full-scale deflexion for correct bridge current) w.w. manganin

R_5 = 70 Ω w.w. manganin

RV_1 = 4 Ω w.w.

RV_2 = 2000 Ω w.w.

S_1 = 3 position, 4 section wafer switch

Th_1 = thermistor in probe, Keystone type L 2008–580–94

Th_2 = thermistor inside hypsometer, type L 2008–580–94

G = meter 100 μA, 176 Ω

The temperature sensitive element is fitted into a probe at the end of 25 ft of cable. This enables the probe to be immersed in a boiling pool while the instrument remains a safe distance away. On the superheat range, the bridge is completed by a reference thermistor (Th_2) similar to the one in the probe. This thermistor is permanently installed inside the hypsometer. The indication on the meter is th difference between the temperature of the probe and th temperature of the reference thermistor (local boiling point). On the temperature range the bridge is completed by manganin resistor R_3 of approximately 68 Ω. The meter i shunted to extend its range, and is calibrated to read directly

CONSTRUCTION OF THE TEMPERATURE SENSITIV PROBE

It is essential for the probe to be very rugged to withstan the necessarily hard treatment in the field. In addition, must be small to enable it to fit inside the hypsometer fo "boiling point zero" adjustment. For this reason, too, th heat loss by conduction from the tip must be reduced to minimum, otherwise the probe thermistor will not attain th same temperature as the reference thermistor. Initially, brass thimble containing the thermistor was fitted on to Bakelite tube about 4 in. long and $\frac{1}{4}$ in. in diameter. Con tinued immersion in steam and boiling water eventuall broke down the metal-Bakelite seal, and it was decided t construct an all-metal probe.

To reduce the heat loss from the tip to an acceptable figur the body of the probe is finned as shown (*I*, Fig. 1). Thi increases the surface area, and reduces the cross-section area for conduction. Thus the "thermal length" of the prob is increased, with the result that losses from the tip ar negligible when the probe is fully immersed in the hypsometer

The thermistor is soldered into the bottom of a smal thimble and the thimble is soldered to the main body of th probe. Fine insulated leads are taken from the thermisto and the thimble through a hole through the body of th probe and connected to a two-core rubber-covered cable The rubber sheath of the cable is vulcanized on to a rubber clad brass tube as shown, and the probe is screwed on to th other end of the brass tube. The whole assembly is nick plated.

REFERENCE THERMISTOR

The reference thermistor is permanently located inside th hypsometer. The leads from the thermistor are passed u the outer steam jacket and through a gland near the top as shown in Fig. 1. This reduces the heat loss from th thermistor.

The thermistor must be protected from the steam, but n varnish could be found that would withstand steam indef nitely. It was necessary, therefore, to protect the varnish First the thermistor was dipped repeatedly in "Araldite coating varnish until the thermistor and leads were complete insulated. The thermistor was then slightly warmed an painted evenly with colloidal graphite, leaving 1 cm varnished leads clear. It was then copper-plated over th graphite. This form of protection from steam has been foun still effective after some months of use.

LABORATORY TESTS AND CALIBRATION

Tests were done to examine:

(i) the effect of self-heating for various values of current in particular the current used in practice;

(ii) the effect of immersion in different media, namely steam, stirred water, and still water, on self-heatin for a given current;

(iii) the effect of depth of immersion of the probe on th loss of heat from the tip and, consequently, on th indication for a given temperature;

(iv) performance as compared with a standard laboratory hypsometer.

The instrument was found to be satisfactory in all the bove respects.

IMPROVED DESIGN OF HYPSOMETER

An improved hypsometer has been made but this has ot yet been built into a field equipment. The equipment will be considerably more portable than the original because improved design has reduced the current-demand on the battery. This hypsometer has been made in the form of a Dewar flask. It contains less water than the other instrument and can be maintained in a boiling state on 1 W. To reach the boiling state requires 5 W for 5 min. A suitable battery for two or three days' field work need therefore weigh only about 4 lb.

An integrating microdensitometer for biological cells

By E. M. Deeley, B.Sc., Ph.D., Wheatstone Physics Laboratory, King's College, University of London

[*Paper first received* 25 *June, and in final form* 22 *December*, 1954]

A photoelectric method for the rapid determination of the total absorption of biological cells is described. The image of the cell, formed by a microscope, is scanned by a mechanically-driven aperture behind which is mounted a photomultiplier. A logarithmic circuit is used in conjunction with an electric integrator giving a meter reading linearly related to the total absorption. The scanning time is three seconds and it is possible to measure at least forty cells per hour. The mean random error is not more than 2% for most objects studied, and the error due to inhomogeneous distribution in one plane is negligible. Systematic error due to glare and other optical effects is of the order of 2%.

1. INTRODUCTION

Microphotometric measurements on biological preparations re now used extensively in studying the relative amounts nd behaviour of certain chemical constituents of cells, naking use of the natural light absorption of these constituents and the absorption of certain stains. In several nethods which have been described(1,2,3) serious errors may e incurred when the distribution of the material over the rea measured is not uniform (see, for example, Davies and Walker(4)) while other methods designed to overcome this isadvantage are relatively slow and laborious.(5,6,7) There s a need for an instrument which enables the total absorption of a cell to be measured rapidly so that large quantities of iological material can be surveyed in a short time, and to an ccuracy of a few per cent.

If a narrow pencil of light traverses an absorbing layer ith a surface concentration dM/dA, where M is the amount of material and A the area, from the Beer–Lambert law the ntensity I_t of the transmitted light bears the following elation to the intensity I_0 of the incident light:

$$\log I_0/I_t = k(dM/dA) \text{ (where } k \text{ is constant)}$$

lternatively:

$$dM/dA = (1/k)\log I_0 - (1/k)\log I_t$$

f, therefore, a layer with a non-uniform surface concenration is illuminated, the total amount M of absorbing aterial within an area A can be calculated by the surface ntegral:

$$\int_A [(1/k)\log I_0 - (1/k)\log I_t]dA$$

This integral is, in effect, derived by the instrument now to e described, and it is therefore apparent that it is not necesary to illuminate the specimen uniformly. A small moving perture is provided in the image plane of a microscope ocused on the specimen being measured. Behind this noving aperture is mounted a fixed photocell.

If light of intensity I is permitted to pass through an aperture of area δA on to a photocell, the current generated at the photocathode will be equal to $KI\delta A$, where K is a constant depending on the sensitivity of the photocathode which will vary according to the position of δA in the field. If the currents actually generated at the photocathode, with the specimen in position and out, are i_t and i_0, M will be given by

$$\int_A [(1/k)\log(i_0/K\delta A) - (1/k)\log(i_t/K\delta A)]dA$$

which is equal to

$$(1/k)\int_A \log i_0 dA - (1/k)\int_A \log i_t dA$$

Thus, as the aperture scans the image field any variations in K and δA have no effect on the calculation of M.

The photocell is of the photomultiplier type. This permits the use of the circuit described by Sweet(8) which yields a voltage proportional to $\log i$. A voltage integrating circuit then gives a signal V proportional to $\int -\log i\, dt$. If, therefore the scanning spot is made to move so that dA/dt is constant, M will be proportional to $V_t - V_0$, the difference between the output voltages of the instrument with and without the specimen in position.

The aperture moves across the image in a series of parallel straight lines at nearly uniform linear speed. The non-uniformity in linear speed has a maximum value of $\frac{1}{2}$% so that the error introduced is negligible. The aperture is almost square (slightly rhombic) in shape, of side almost double the interval between the lines. The summation of $\log i$ is therefore not a true integral but nearly proportional to the integral, provided that the absorption does not vary appreciably over distances less than the side of the aperture.

In practice, objects are three-dimensional so that errors in microphotometric measurements may occur (see, for example, Davies and Walker(4)) due to parts of the object lying outside the depth of focus of the microscope objective. Further errors may also arise from the apparent increase in extinction due to some rays from the condenser passing obliquely through the object, and glare, i.e. unwanted stray light, falling within the region of the image. These errors, which increase with optical extinction, are reduced to a minimum in this instrument by the use of a technique described by Davies, Wilkins and Boddy(9) whereby the specimen may be crushed by a specially designed condenser. This has the effect of redistributing the material effectively into one plane and reducing the optical extinction.

2. THE OPTICAL SYSTEM

The specimen, which is mounted on a specially constructed mechanical stage *N* (Fig. 1), fitted with micrometer adjustments, is illuminated according to Köhler with monochromatic light selected by filters from a 125 W mercury-vapour lamp (a B.T.H. type MB/D stabilized arc). Glare in the system is reduced to a minimum by using field stops which just fill the required field. These are in the form of pinholes mounted on a rotating nosepiece, *R*. A glass cover-slip *B* mounted at 45° to the optic axis reflects a small fraction of the light so that an image of the field stop is focused by the lens *L* on to an aperture *H*. The light passing through *H* is scattered by a ground-glass screen on to the cathode of the photomultiplier PM_2 (an R.C.A. type 931-A) which is used to stabilize the brilliance of the mercury-arc lamp *A* in a manner described in Section 4.4. A circular photographic density wedge *W* is used to regulate the light level in the microscope. The condenser used is either the specially designed crushing condenser(9) or a Cooke 1·3 n.a. oil immersion stopped down to a maximum of 0·8 n.a. The objectives used are a Watson 2 mm apochromat and a Zeiss 0·85 n.a. $\frac{1}{7}$ in. oil immersion.

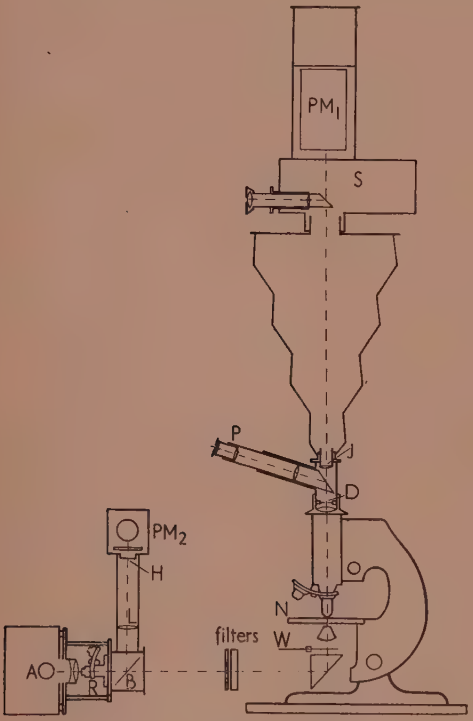


Fig. 1. The optical system

A removable viewing eyepiece *P* is used to examine the image of the specimen formed at the iris diaphragm *D* b the objective of the microscope (a Beck model 47). Whe this eyepiece is withdrawn the projection lens *J* forms magnified image of the iris diaphragm on the rotating dis of the scanner *S*. A second viewing eyepiece mounted imme diately below the scanning disk is used to ensure that th image is correctly positioned with the scanned area which defined by a stop 1 cm in diameter. Leather bellows preven stray light from entering the system.

3. THE SCANNING MECHANISM

The position of the scanning aperture at any moment determined by the intersection of two narrow slits which ar approximately at right angles to one another. Twent radial slits 0·2 mm in width and 8 mm in length are cu around the circumference of the disk *F* (10 cm in diamete which is mounted on the spindle of a 60 rev/min synchronou motor (see Fig. 2). The motor and disk are mounted on plate *G* which is held by ball bearings so that it may be move to and fro by rotation of the cam *Q*. This cam is drive through two gear wheels (ratio 1 : 3) from the synchronou motor, so that as the plate *G* moves through one complet cycle consisting of a rapid "flyback" period followed by linear movement back to its original position, radial slot pass across the scanned area a total of ninety times. plate *K*, which carries a further slot 0·2 mm in width an 15 mm in length, is also mounted on *G* so that the imag field is effectively scanned by a small aperture moving in series of parallel lines. A microswitch *MS* is used to stop th synchronous motor at the end of each cycle of ninety line (see Section 4.3). The maximum variation from 90° in th angle between the slits forming the aperture is 6° so that th corresponding variation in the scanning rate is of the orde of 0·5%.

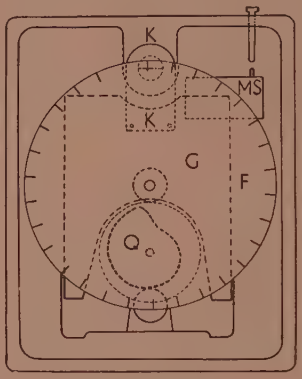


Fig. 2. The scanning mechanism

4. ASSOCIATED ELECTRIC CIRCUITS

4.1 *The photomultiplier circuit.* The method of obtaining voltage proportional to the logarithm of the light intensit on the photocathode depends on a property of photomultiplier utilized by Sweet.(8)

The anode current i in a photomultiplier is:

$$i = aIv^n$$

(where I is the light intensity, a is a constant, v is the voltag between successive dynodes, and n is a constant, equa theoretically to half the total number of multiplication stages

The dynodes are supplied from a series chain of resistances
that the voltage between successive dynodes will be pro-
ortional to v_0 the overall voltage across the chain. If v_0 is
ontinuously regulated so that the current i is kept constant
t all light intensities, it follows[(8)] from the above equation
hat:

$$dv_0/d\log I = -v_0/n$$

hus the smaller the variation in v_0, the more linear is the
elationship between v_0 and log I, and hence n should be as
rge as possible. For this reason a fourteen-stage photo-
ultiplier (type 6685) is used.

The photomultiplier PM_1 and the associated circuits of
alves V_5 and V_6 (Fig. 3) comprise a negative feedback
rcuit which acts so as to keep the voltage across R_8, and
ence the current i, almost constant. The cathode of PM_1
connected to a voltage of $-1{\cdot}5$ kV supplied from a
abilized power pack. The voltage v_0 therefore depends on
e cathode voltage of V_6 which, in practice, varies between
bout -50 and 320 V according to the light intensity on the
otocathode. The diodes V_1, V_2 and V_3 have the effect
progressively reducing the voltage across R_8 as v_0
creases, so as to correct the non-linearity due to the
esence of the term v_0 in the expression for $dv_0/d\log I$. By
justment of the resistors R_1, R_2 and R_3, v_0 is made to
ry linearly with extinction over the range 0 — 1 with an
curacy of better than 1%.

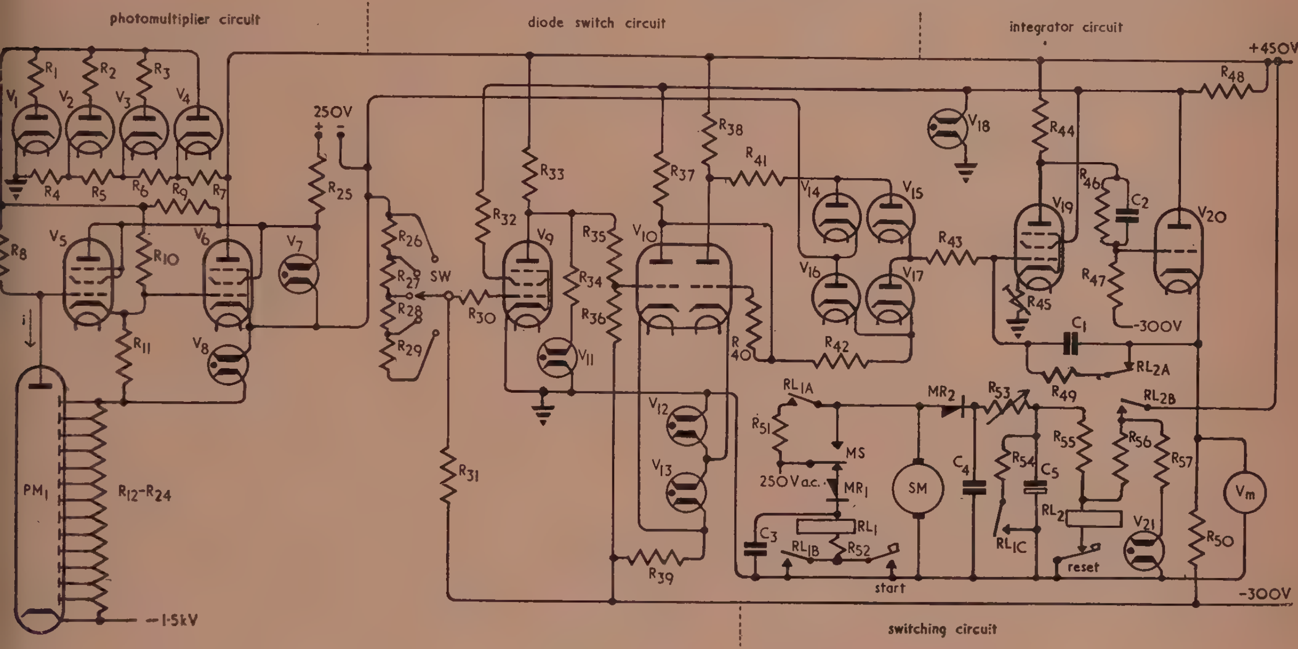

photomultiplier circuit
diode switch circuit
integrator circuit
switching circuit
+450V
250V
-300V
-1·5kV
250V a.c.
R_1
R_2
R_3
R_4
R_5
R_6
R_7
R_8
R_9
R_{10}
R_{11}
R_{12}–R_{24}
R_{25}
R_{26}
R_{27}
R_{28}
R_{29}
R_{30}
R_{31}
R_{32}
R_{33}
R_{34}
R_{35}
R_{36}
R_{37}
R_{38}
R_{39}
R_{40}
R_{41}
R_{42}
R_{43}
R_{44}
R_{45}
R_{46}
R_{47}
R_{48}
R_{49}
R_{50}
R_{51}
R_{52}
R_{53}
R_{54}
R_{55}
R_{56}
R_{57}
V_1
V_2
V_3
V_4
V_5
V_6
V_7
V_8
V_9
V_{10}
V_{11}
V_{12}
V_{13}
V_{14}
V_{15}
V_{16}
V_{17}
V_{18}
V_{19}
V_{20}
V_{21}
C_1
C_2
C_3
C_4
C_5
SW
i
PM_1
RL1A
RL1B
RL1C
RL1
RL2A
RL2B
RL2
MR1
MR2
MS
SM
Vm
start
reset

Fig. 3. Circuit of integrating densitometer

$R_1 = 4$ MΩ
$R_2 = 6{\cdot}6$ MΩ
$R_3 = 20$ MΩ
R_4, $R_5 = 100$ kΩ
R_6, $R_7 = 150$ kΩ
$R_8 = 3{\cdot}3$ MΩ (h.s.)
$R_9 = 470$ kΩ
$R_{10} = 47$ kΩ
$R_{11} = 270$ kΩ
R_{12}–$R_{24} = 13 \times 47$ kΩ
$R_{25} = 47$ kΩ
R_{26}–$R_{30} = 470$ kΩ
$R_{31} = 2{\cdot}2$ MΩ
$R_{32} = 47$ kΩ
$R_{33} = 270$ kΩ
$R_{34} = 1$ MΩ
$R_{35} = 2{\cdot}2$ MΩ

$R_{36} = 1{\cdot}5$ MΩ
R_{37}, $R_{38} = 100$ kΩ
$R_{39} = 15$ kΩ
$R_{40} = 2{\cdot}2$ MΩ
R_{41}, $R_{42} = 1$ MΩ
$R_{43} = 3{\cdot}3$ MΩ (h.s.)
$R_{44} = 100$ kΩ
$R_{45} = 500$ Ω
$R_{46} = 2{\cdot}2$ MΩ
$R_{47} = 2{\cdot}7$ MΩ
$R_{48} = 27$ kΩ
$R_{49} = 2{\cdot}2$ kΩ
$R_{50} = 100$ kΩ
$R_{51} = 200$ Ω
$R_{52} = 100$ kΩ
$R_{53} = 50$ kΩ
$R_{54} = 2{\cdot}2$ kΩ

$R_{55} = 47$ kΩ
$R_{56} = 470$ kΩ
$R_{57} = 750$ kΩ
RL_1, $RL_2 = 20$ kΩ

$C_1 = 1$ μF
$C_2 = 47$ pF
C_3, $C_4 = 0{\cdot}5$ μF
$C_5 = 8$ μF

V_1–$V_4 = \frac{1}{2}$ EB.91
V_5 = ME1400
V_6 = EF54
V_7 = 85A2
V_8 = 150B2
V_9 = EF54

V_{10} = 6SN7
V_{11} = G.E.C. "Tuneon"
V_{12}, V_{13} = VS70
V_{14}–$V_{17} = \frac{1}{2}$ EB.91
V_{18} = 150B2
V_{19} = EF54
V_{20} = 6J5
V_{21} = G.E.C. "Tuneon"

PM_1 = type 6685

SM = "Synclock" type MBS

V_m = 10 V (100 μA) full scale

MR_1, MR_2 = H.100

4.2 *The diode switch.* When no light falls on the cathode of the photomultiplier PM_1 the extinction is theoretically infinite, and the voltage v_0 rises to its maximum value. (This is limited to about 1820 V by the diode V_4.) It is obvious, however, that the process of integration should proceed only when light is falling on the photocathode, and for this reason a diode switch is incorporated which disconnects the input of the integrator from the photomultiplier circuit when v_0 rises above a certain value.

The resistance R_{31} (Fig. 3) is so chosen that V_9 conducts when v_0 is greater than a value corresponding to extinctions of 0, 0·25, 0·75 or 1·0 respectively, depending on the setting of the switch SW. The anode voltage of the left-hand triode of V_{10} then rises from about -150 to 180 V, while that of the right-hand triode falls from about 400 to -90 V. These voltages are used to control the current in the diodes $V_{14}-V_{17}$ which therefore conduct only when the extinction is lower than one of the values selected by SW. Since the anode-cathode voltage of the diodes when conducting is only a fraction of a volt, the output voltage is equal to v_0. At high values of extinction no current flows in the diodes, and the output terminal is isolated from v_0. The operation of the diode switch is indicated by the lighting of the neon tube V_{11}.

4.3 *The integrator and switching circuit.* The integrator is of the Miller type (see, for example, reference 10), comprising a voltage amplifying pentode V_{19} d.c.-coupled to a cathode follower V_{20}. In this circuit, the voltage on the cathode of V_{20}, which is recorded by the meter V_m, varies linearly with the time integral of the input voltage. This is only strictly accurate if the voltage gain of the amplifier is infinite, but the error introduced is negligible in comparison with those from other sources.

The purpose of the switching circuit is to allow the scanning mechanism to perform one complete cycle on depressing the "start" button. This operation also starts the integration process by removing a short circuit across C_1 after the flyback period mentioned in Section 3 is complete. The microswitch *MS* mounted on the plate *G* (Fig. 2) is held in the open position at the end of each scan by the action of a small screw fixed to the casing of the scanning mechanism. When the "start" button is momentarily depressed, the relay RL_1 closes so that an a.c. voltage is supplied to the scanning motor, first through the contacts RL_{1A} and then through the microswitch *MS*, throughout the scanning period. The action of the time constant $R_{53}C_5$ ensures that the relay RL_2 closes a short time after the commencement of the scan, thus opening the contacts across C_1. In order that the reading of the meter V_m can be taken, this relay is self-maintained through the contacts RL_{2B} until the "reset" button is depressed. The neon tube V_{21} provides visual indication of the operation of the relay.

4.4 *Mercury lamp stabilizer.* Short term fluctuations in the intensity of the mercury-arc lamp, which could cause large errors in the estimation of the total amount of stain, are reduced to a negligible amount by the operation of the circuit shown in Fig. 4. The lamp, which normally operates at about 80 V, draws a current of approximately 1·2 A from the 200 V d.c. mains supply through the resistances R_{26} and R_{27} and also a further current of between 0 and 300 mA from a power supply incorporating the valves V_1 and V_2. This latter current flows through the four beam power tetrodes V_5, V_6, V_7 and V_8 connected in parallel, and is controlled by the anode voltage of the photomultiplier PM_2 through the voltage amplifying triodes V_3 and V_4. The photomultiplier PM_2 receives a small amount of light from the lamp in a manner described in Section 2, thus completing a negative feedback circuit which ensures that the anode PM_2 remains at approximately earth potential. The ano current of PM_2, and hence the brilliance of the lamp, therefore stabilized at a value depending on the anode loa resistance R_1. The push-button switch *SW* is used to stri the mercury-arc by momentarily connecting it to a hig voltage through the resistance R_{25}. The dynodes of t photomultiplier PM_2 are supplied from ten 90 V batteri connected in series.

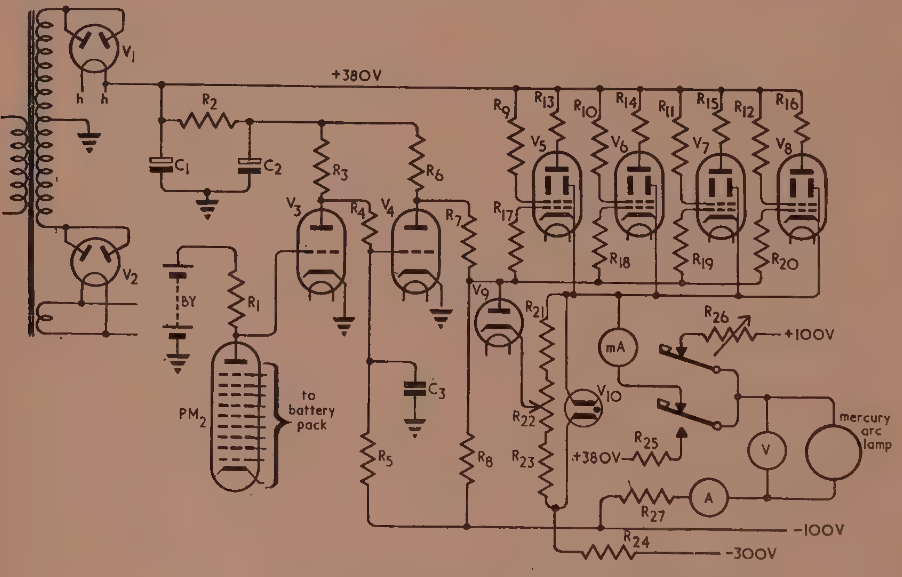


Fig. 4. Mercury-arc lamp stabilizing circuit

$R_1 = 2$ MΩ (h.s.)
$R_2 = 22$ kΩ
$R_3 = 100$ kΩ
$R_4 = 270$ kΩ
$R_5 = 150$ kΩ
$R_6 = 100$ kΩ
$R_7 = 270$ kΩ
$R_8 = 200$ kΩ
R_9–$R_{16} = 47$ Ω
R_{17}–$R_{20} = 4·7$ kΩ
$R_{21} = 10$ kΩ
$R_{22} = 20$ kΩ
$R_{23} = 27$ kΩ
$R_{24} = 75$ kΩ
$R_{25} = 2$ kΩ (w.w.)
$R_{26} = 70$ Ω (w.w.)
$R_{27} = 40$ Ω (w.w.)

$C_1 = 64$ μF
$C_2 = 34$ μF
$C_3 = 0·01$ μF

mA = 0–500 mA
A = 0–3 A
V = 0–150 V

V_1, V_2 = 5U4G
V_3, V_4 = ½ 6SN7
V_5, V_6, V_7, V_8 = 807
V_9 = EA.50
V_{10} = VS70

PM_2 = RCA 931-A
BY = 30 V

5. PERFORMANCE AND DISCUSSION

The purpose of the tests described below was to determi the error arising from various causes in the measurements total absorption.

Random fluctuations. Without moving the specime small variations in successive readings of the integrator ou put voltage are found to occur due to photomultipli fluctuations and small irregularities in the operation of t scanning mechanism [see Fig. 5(*a*)]. In practice the effe of these variations is reduced by taking the mean of thr successive readings for each object and subtracting the mea of three readings for clear field. The resulting random err in the stain content is therefore largest for a small, light stained object, for example a ram sperm head stained wi Feulgen, for which the mean error is of the order of $\pm 1\frac{1}{2}$ For the majority of objects studied this figure is less tha ±1%. Fig. 5(*b*) illustrates the results of twenty-four indi pendent determinations of the Feulgen stain in a single ra sperm head with respect to various positions in the cle field. From a comparison with Fig. 5(*a*) it appears th there are only small errors due to selecting different clea field positions for the reference reading, to refocusing t specimen between each determination, and to moving t image of the specimen to various positions within the scanne field. (These results are similar to, but not the same as tho already published.(11))

Linearity of output. Two methods have been used examine the extent to which the output reading of the instr ment is proportional to the total amount of stain in materi measured. In the first of these, use is made of the resu hat the amount of stain in ram sperm heads appears to ave a very constant value. The average amount of stain in ne sperm head, as calculated from measurements on thirty pecimens [see Fig. 5(*c*)] is compared graphically in Fig. 6 vith the amount of stain in each of several groups of two or nore sperm heads. (In some groups the specimens are side y side, while in others they overlap to varying extents.) It an be seen that the amount of stain in each group correponds to a multiple of the average stain in each specimen to vithin the expected variation due to the material. In the cond method, the sum of the readings for each of two eighbouring cells of onion root tip has been compared with e reading obtained when both cells are measured together. he difference in the amounts so obtained is less than the andom error of the instrument (of the order of 1% for this aterial).

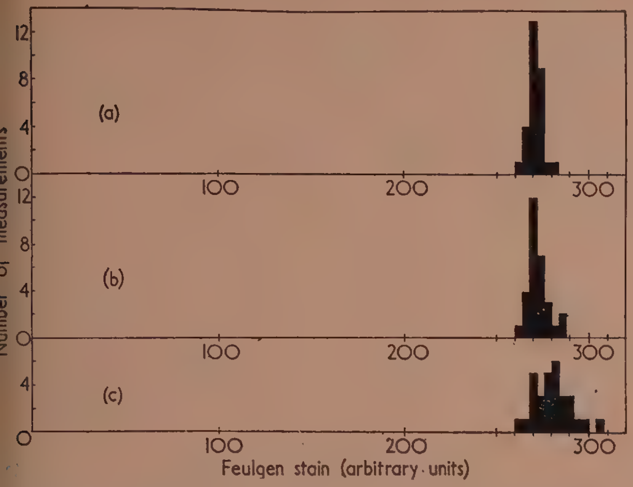


Fig. 5. (*a*) Spread of results due to random error. (*b*) Measurements on a single sperm head. (*c*) Measurements on a collection of sperm heads

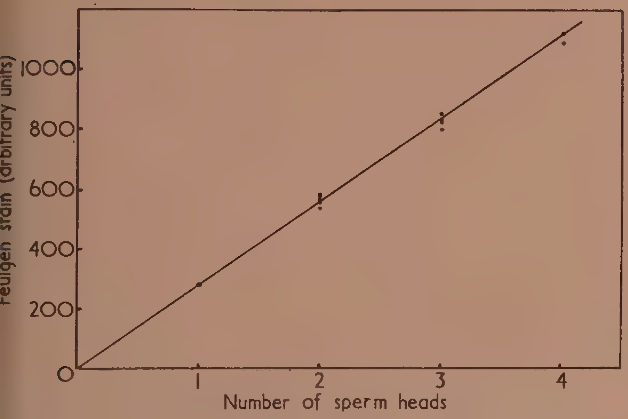


Fig. 6. Relation between number of sperm heads and stain content

Distributional effects. The measurements of the amount f stain in sperm heads shows that the results obtained by is instrument are independent of the way in which the aterial is distributed within the scanned field. This has een further demonstrated by making use of the crushing chnique(9) which has been used to redistribute in one plane e material of Feulgen stained cells of onion root tip. When nuclei of various forms are crushed until the whole material lies within the depth of focus of the microscope (the average optical extinction being of the order of 0·4 in this instance) it is found that the measured amount of stain is independent of further crushing to within the random error of the instrument.

Defocusing and glare. For most of the cells studied with this instrument the effect of defocusing has been found to be small. For cells of low extinction (less than 0·2) the reduction in reading is less than 2%, even when the object is so out of focus that all detail is lost. For a cell of mean extinction of 0·5 a reduction of 8% was recorded with a similar degree of defocusing. For cells having an extinction less than 0·5 the effect of a small amount of defocusing is negligible.

The glare in the system, measured within the image of a small opaque body (an iron sphere approximately 5 μ in diameter) is less than 1% of the intensity of the incident light, corresponding to an error of less than 1½% at an extinction of 0·4.

This instrument has been applied to a wide range of Feulgen-stained cells of plant and animal tissue, some of which results have been published elsewhere.(11) It has proved to be at least as accurate and, when applied with crushing to dense inhomogeneous objects, far more rapid, than any other method so far described. Under normal conditions it is possible to measure approximately forty nuclei per hour.

This instrument has not so far been used extensively with any stains other than the Feulgen stain, for which the 546 mμ mercury line is used, although its application can be extended without major modification to stains absorbing at the violet (435 mμ) or yellow (576 mμ) lines of the mercury spectrum.

ACKNOWLEDGEMENTS

The author would like to express his grateful thanks to Professor J. T. Randall, for his constant interest and encouragement in the course of this work; to Dr. P. M. B. Walker for his advice and assistance; and to Dr. H. G. Davies and Dr. M. H. F. Wilkins for frequent discussions. The mechanical details of the scanning mechanism were designed by Dr. Walker and the mechanism was constructed by the staff of the King's College workshops. The author is indebted to the Nuffield Foundation for a Fellowship.

REFERENCES

(1) Lison, L. *Acta Anatomica*, **10**, p. 333 (1950).
(2) Swift, H. H. *Physiological Zoölogy*, **23**, p. 169 (1950).
(3) Pollister, A. W., and Ris, H. *Symposia on Quantitative Biology*, **7**, p. 147 (Cold Spring Harbor: Biological Laboratory, 1947).
(4) Davies, H. G., and Walker, P. M. B. *Progress in Biophysics* (Edited by Butler and Randall), **3**, p. 195 (London: Pergamon Press, 1953).
(5) Caspersson, T. *Experimental Cell Research*, **1**, p. 595 (1950).
(6) Walker, P. M. B., and Yates, H. B. *Proc. Roy. Soc. B*, **140**, p. 274 (1952).
(7) Caspersson, T., Jacobson, F., and Lomakka, G. *Experimental Cell Research*, **2**, p. 301 (1951).
(8) Sweet, M. H. *Electronics*, **19**, (11), p. 105 (1946).
(9) Davies, H. G., Wilkins, M. H. F., and Boddy, R. G. H. B. *Experimental Cell Research*, **6**, pp. 550–553 (1954).
(10) Korn, G. A. *Electronics*, **21**, p. 122 (1948).
(11) Deeley, E. M., Davies, H. G., Richards, B. M., and Walker, P. M. B. *Experimental Cell Research*, **6**, p. 569 (1954).

A general-purpose 50 c/s null indicator, particularly suitable for us with high-voltage bridges

By W. P. Baker, B.Sc., A.M.I.E.E., Metropolitan-Vickers Electrical Co. Ltd., Trafford Park, Manchester

[*Paper first received* 31 *January, and in final form* 22 *March*, 1955]

When a null indicator is used with a high-voltage bridge the additional requirement must be met of suppressing the output voltage due to discharge currents in the test specimen or connexions. A new approach to the design of a null indicator is described which not only yields a satisfactory solution to the discharge problem but also produces an instrument which is simpler, cheaper and more effective than conventional indicators. The new design is basically a tapered low-pass resistance-capacitance filter in which some of the passive resistive elements have been replaced by the anode impedances of amplifying valves.

For many years the detection of null conditions in 50 c/s bridges has been accomplished by means of vibration galvanometers. It is worth listing the requirements of null indication in order to establish the shortcomings of this instrument.

(1) The indicator should accept 50 c/s signals and should reject harmonic signals.

(2) Band-width should not be sacrificed in order to gain sensitivity and/or selectivity.

(3) The sensitivity should not be less than 20 μV.

The vibration galvanometer has an effective Q-factor of about 1000 and hence the rejection of third harmonic currents is satisfactory provided the tuning is perfect; a difference of 0·1 c/s between the applied and the resonant frequencies reduces the sensitivity and the third harmonic rejection by a factor of 4. Requirement No. 2 is therefore not fulfilled and the critical nature of the tuning of the instrument is its principal disadvantage.

Many research workers in recent years have appreciated the foregoing, and a number of electronic null indicators have been described.(1, 2, 3) Some of these indicators have been tunable over the audio-frequency range by means of switched resistance-capacitance feedback filter networks (generally parallel T-networks).(2) The equivalent Q-factor of a selective feedback amplifier of the parallel T-type is approximately one-half the amplifier gain (without feedback) between the ends of the filter.

It has generally been found impossible to apply the feedback over more than one stage without introducing instability, and this drawback has limited the effective selectivity of the indicators. To offset this it has occasionally been the practice to use two separate filtered stages, a practice which leads to an increased number of amplifying stages and which decreases the band-width seriously. One American firm has gone to the length of having two filtered stages and two phase-sensitive dynamometer instruments to eliminate harmonic voltages.

Implied in this published work is a general realization that there is a need for an improvement in discrimination over the simple parallel T-type of amplifier. When the null indicator is to be used in conjunction with a high-voltage bridge, the additional requirement arises of rejecting the unbalanced voltages resulting from high-energy corona discharge currents which may appear across the balance terminals of the bridge. Consideration of this further problem has led to the development of a null indicator based on a new design principle and having a performance better than conventional types, and yet which is very simple.

PRINCIPLE OF OPERATION

The frequencies of the currents flowing from the terminals of the bridge as a result of corona discharge extend into the megacycle region, the energy per octave rising with frequenc for a Schering bridge. To eliminate these currents from th null indicator, a low-pass filter may be interposed betwee the bridge and the indicator. A resistance-capacitance for of filter is necessary to avoid the elaborate screening require to reduce the 50 c/s voltages induced by stray fields i inductance elements.

Having established the need for a resistance-capacitanc low-pass filter, it remains to examine the operation of such filter in the rejection of third harmonic voltages. It follow that if this rejection is satisfactory, then the low-pas characteristics of the filter would render the performanc with respect to discharge currents more than satisfactory.

Consider a simple resistance-capacitance filter network a shown in Fig. 1. The ratio (output voltage at 50 c/s)/(outpu voltage at 150 c/s) does not increase in proportion to th number of elements because of the loading effect of each ne section on the earlier sections. However, if the filter b modified by progressively increasing the impedance of eac stage a times, as shown in Fig. 2, then, provided the valu of a were great enough, a negligible load would be impose by each successive section and the total value of the voltag ratio would be equal to the voltage ratio per section multiplie by the number of sections. In order to achieve this effect th value of a should not be much less than ten, and this impose a limit on the number of sections of the filter since a rang of more than three decades is difficult.

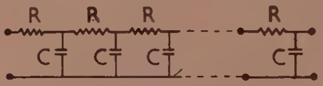


Fig. 1. Simple low-pass resistance-capacitance filter

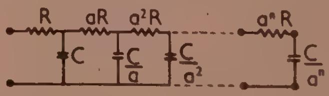


Fig. 2. "Tapered" low-pass resistance-capacitance filter

This difficulty may be overcome fairly simply by replacin every third passive resistance element of the network by th anode impedance of an amplifying valve. The impedanc conversion of the valve stage then enables any number c elements to be cascaded.

DESIGN BASIS

There is no obvious limit to the degree of attenuation c higher harmonics that may be obtained, just as there is n limit to the amplification obtainable apart from noise cor siderations. To consider the design of the null indicator i purely general terms, therefore, would be wasteful, and it referable to start from the statement of requirements made t the beginning of this paper, quoting a value of about 00 times as the minimum acceptable third harmonic rejection.

To obtain the necessary sensitivity three stages of amplication would normally be necessary, and the number of lter sections used to give the required third harmonic rejection ay be based on this number of stages. These considerations t the number at 7 (or 8 if the primary side of a matching ansformer be included).

The voltage ratio (input/output) per section must next be ecided upon. If each series element be made numerically qual to its shunt element at 50 c/s, the voltage ratio at 50 c/s $\sqrt{2}$ and is $\sqrt{10}$ at 150 c/s giving a rejection ratio of $\sqrt{5}$. even such elements produce a rejection ratio of 500 and a oltage ratio at 50 c/s of 11·3. Reducing the voltage ratio er stage by making $\omega CR = 0{\cdot}8$ reduces the rejection and oltage ratios to 144 and 5·7 times respectively, and increasing CR to 1·4 increases the ratios to 630 and 44 times in turn.

The value of $\omega CR = 0{\cdot}8$ would seem to be the best ompromise if sensitivity were very important, but for a eneral purpose indicator the value of unity appears to be nost attractive, as shown by the value of an arbitrary figure f merit obtained by dividing the rejection ratio by the voltage atio at 50 c/s. These figures of merit are 25, 44 and 14 for $CR = 0{\cdot}8$, 1·0 and 1·4 respectively. The higher rejection alue is necessary to counterbalance the high-pass effect of oupling condensers.

Three pentode stages would result in a sensitivity much etter than 10 μV, and a considerable saving in space and omponents may be effected by the use of one pentode and double triode. A further advantage acrues from the use f a double triode, as will be explained later.

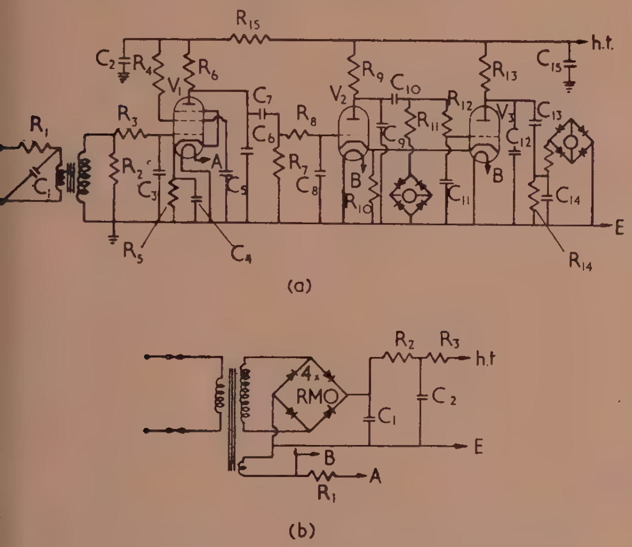


Fig. 3. Complete circuit diagram of null indicator

(*a*) Indicator unit.

$R_1 = 33$ kΩ
$R_2 = 1$ MΩ
$R_3 = 330$ kΩ
$R_4 = 10$ MΩ
$R_5 = 22$ kΩ
$R_6 = 3{\cdot}3$ MΩ
R_7, $R_8 = 10$ MΩ
$R_9 = 33$ kΩ
$R_{10} = 47$ Ω
$R_{11} = 100$ kΩ

$R_{12} = 1$ MΩ
$R_{13} = 33$ kΩ
$R_{14} = 100$ kΩ
$R_{15} = 100$ kΩ

$C_1 = 0{\cdot}1$ μF
$C_2 = 16$ μF
$C_3 = 0{\cdot}01$ μF
$C_4 = 30$ μF
$C_5 = 0{\cdot}1$ μF

$C_6 = 0{\cdot}001$ μF
$C_7 = 0{\cdot}1$ μF
$C_8 = 0{\cdot}001$ μF
C_9, $C_{10} = 0{\cdot}1$ μF
$C_{11} = 0{\cdot}01$ μF
C_{12}–$C_{14} = 0{\cdot}1$ μF
$C_{15} = 8$ μF

$V_1 =$ EF37A
V_2, $V_3 = \frac{1}{2}$ ECC91

(*b*) Power unit.

$R_1 = 15$ Ω
R_2, $R_3 = 10$ kΩ
$C_1 = 8$ μF
$C_2 = 16$ μF
RMO = selenium rectifier type RMO

The use of direct current for valve heaters is to be avoided, if possible, if the equipment is to be kept simple, and a form of hum balancing may be used if the instrument is in continuous use. The long period of stabilizing time attendant on a balancing arrangement is a serious drawback if the equipment is used only occasionally, however, and a better arrangement is the use of a special low-noise pentode operating under electrometer conditions.

The full-scale current of the indicating instrument may be chosen within wide limits on a basis of cheapness and availability; the output stage may then be designed to supply the chosen value of current. There is then no danger of damaging the instrument by an overload resulting from a serious unbalance condition of the bridge. A value of 1 mA was decided upon, and the theoretical design resulting from these considerations is shown in Fig. 3.

FINAL DESIGN

The design shown in Fig. 3 does not include a sensitivity control, and rather than include a variable element or potentiometer an alternative was sought. Since both halves of the double triode are identical each may equally well operate as an output stage, and the first half may be used to drive an indicator at lower sensitivity to be used when the final stage is saturated.

General details. The physical simplicity of the developed circuit in being free from chokes and variable elements has enabled the complete indicator to be accommodated in two small cabinets. The power supplies—which it is desirable to keep separate from the amplifier—are contained in a box 6 × 5 × 4 in., and the indicator proper is pushed from below into a cabinet 7 × 5 × 4 in.

Performance. The null indicator, when tested, was found to have a sensitivity of 10–20 μV, and the attenuation of third harmonic was about 130 times. The dynamic range of the instrument was over 10 000 (80 dB).

CONCLUSIONS

A departure from the traditional methods of null indicator design has resulted in an instrument of unusual simplicity and improved electrical performance. The rejection of third harmonic signals is about four times better than instruments of comparable size, and the discrimination against discharge when used with a high-voltage Schering bridge is many times better than other types of detector so far described in the literature. It has been found possible to avoid the use of any variable element or tuned circuit, and it is not necessary to specify any component value to an accuracy greater than ±20%. The performance of the instrument is therefore sensibly independent of component variations or aging.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. Willis Jackson, Director of Research and Education, and Mr. B. G. Churcher, Manager of Research Department, Metropolitan-Vickers Electrical Co. Ltd., for permission to publish this paper.

REFERENCES

(1) Banner, E. H. W. *Electronic Engng*, **21**, p. 248 (1949).
(2) Scroggie, M. G. *Wireless Wld.*, **57**, p. 175 (1951).
(3) Looms, J. S. T. *J. Sci. Instrum.*, **30**, p. 290 (1953).

A method of estimating photomultiplier pulse durations and shape

By B. Meltzer, B.Sc., Ph.D., J. A. Lodge, B.Sc., and P. L. Holmes, B.Sc., E.M.I. Research Laboratories Ltd., Hayes, Middlesex

[*Paper first received* 10 *August*, 1954, *and in final form* 23 *March*, 1955]

The measurement of the output spectrum of a photomultiplier is proposed for obtaining information on the duration and shape of the current pulse, which is useful for an estimate of resolving time and for the design of pulse-shaping circuits. Some experimental tests are described.

Information on the resolving time and current pulse shape of a photomultiplier is deducible from the frequency spectrum of its output. A single electron ejected from the photocathode by an incident photon gives rise by secondary emission at successive dynodes to an output current into the collector of many millions of electrons; these together constitute the current pulse. In the dark, the emission of electrons from the photocathode is random, being thermionic or due to penetrating radiation; when the multiplier is steadily illuminated, the emission is still random because the photons arrive randomly. In either case, the full output consists of the superposition of single pulses randomly distributed in time.

The spectral output is therefore given by the Fourier transforms of the current pulses. More specifically (cf. Sard⁽¹⁾), if $F(t)$ is the function of time representing the collector current during a single pulse and

$$g(2\pi f) = \int_{-\infty}^{\infty} F(t) \exp(-i2\pi f t) dt$$

is its Fourier transform, then the mean square current in the frequency range f to $(f + \Delta f)$ is given by

$$\overline{i^2} = 2I\Delta f \frac{|g(2\pi f)|^2_{average}}{[g(0)]_{average}} \qquad (1)$$

Here I is the average direct current.

It follows that, if the pulses are rectangular in shape, each lasting a time τ and carrying a charge Ne, the mean square current is given by

$$\overline{i^2} = 2NeI\Delta f[(\sin \pi f\tau)/(\pi f\tau)]^2 \qquad (2)$$

If the pulses are Gaussian in shape each carrying a charge Ne and characterized by a time τ defined as the duration of a rectangular pulse of the same amplitude which carried the same total charge, the spectrum is itself Gaussian in shape and given by

$$\overline{i^2} = 2NeI\Delta f \exp(-2\pi f^2\tau^2) \qquad (3)$$

If we take into account the fact that the total multiplication factor N is not the same for all pulses, then N in the two formulae must be replaced by $(N^2)_{average}/N_{average}$.

It will be noticed that for low frequencies $(f \ll 1/\tau)$ the mean square current has the same magnitude as shot noise. As frequency is increased, the r.m.s. amplitude drops to half this value at

$f = 0{\cdot}60/\tau$ for a square pulse

and $f = 0{\cdot}83/\tau$ for a Gaussian pulse

If $\tau = 10^{-8}$ s, say, these frequencies would be respectively 60 Mc/s and 83 Mc/s.

However, measurements of the frequency spectrum enab one to draw conclusions about the actual average shape well as duration of the pulse, and in fact, as is shown belo the most accurate measurements made on an E.M.I. expe mental type photomultiplier have shown the shape to definitely non-Gaussian.

It is clear from equation (1) that a knowledge of t spectrum does not enable us to determine uniquely t current pulses producing it, since it gives only the modulu not the argument, of the Fourier transform. [In the pa ticular cases of symmetrical or antisymmetrical pulses, t pulse form is, however, uniquely determined, as the argumen are then known to be respectively 0 and $(-\pi/2)$.] Th difficulty is similar to that encountered in the interpretatio of X-ray crystal spectra. Nevertheless, the method may useful, especially when combined with other types of invest gation, e.g. the use of scalers or study of oscillograms of t noise output, as well as more direct methods.⁽²⁾

EXPERIMENTAL TESTS

Circumstances prevented completion of the experimen described below. It is thought, however, that the few resul obtained may be of interest.

Measurements were made on an E.M.I. experiment photomultiplier and a Mazda photomultiplier. The arrang ment is shown in Fig. 1. The output from the multiplier w taken through an impedance matching network to a cor mercial communications superheterodyne receiver, whic enabled a very small frequency bandwidth of a few kilocycl per second to be selected. The output was read on a met in the automatic volume control circuit of the receiver.

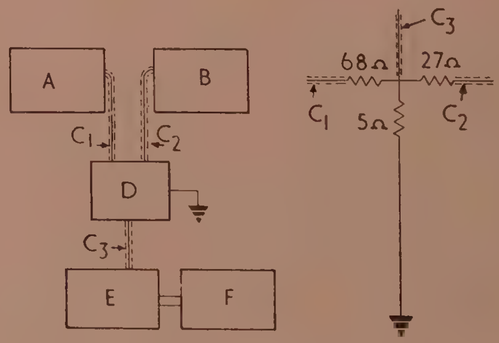


Fig. 1. Block diagram and matching network

A, photomultiplier: *B*, signal generator; *C*₁, 75 Ω shielded cable; *C*₂, 32 Ω shielded cable; *C*₃, short cable; *D*, matching network; *E*, superheterodyne receiver; *F*, output indicator.

andard signal generator was then substituted for the multi- ier and tuned to the receiver, and its output was adjusted give the same reading on the indicator meter as before. ne attenuator reading on the signal generator gave a easure of the photomultiplier output.

The receiver employed covered the range from 30 Mc/s to 0 Mc/s. The photomultiplier fed into a 75 Ω resistor llowed by a 75 Ω shielded cable to the matching network. o minimize the effects of variation of the input impedance the receiver with tuning, the input voltage to the receiver as developed across a very low, 5 Ω, resistance. The output om the multiplier was adjusted to 125 μA by controlling e amount of light falling on its cathode.

In the first measurements, when shielding and decoupling rangements were poor, there was considerable scatter and nevenness in the results when graphed. It seemed therefore asonable as a first approximation, to assume that the pulses ere Gaussian in shape, to plot the logarithm of the output gainst f^2, and draw the best straight line through the points. rom equation (3) above, the negative slope of this should e $\pi\tau^2/2\cdot303$ from which the pulse duration τ could be timated. The results obtained were:

E.M.I.	160 V per stage	$1\cdot2 \times 10^{-8}$ s
Mazda	100 V per stage	$0\cdot7 \times 10^{-8}$ s

In later and more accurate measurements on the E.M.I. ultiplier only, decoupling condensers of 2200 pF each were nnected between successive dynodes of the multiplier and e work was done in a shielded room.

The graph of log (output) against f^2 is shown in Fig. 2, ots and circles representing two independent sets of easurements. As this curve is certainly not a straight line, e average pulse shape is not Gaussian. In the attempt to tain the expression for the pulse shape log (output) was otted against $\log f$, the result being the straight line of g. 3, the slope of which gives the law

$$(\overline{i^2})^{\frac{1}{2}} \propto f^{-1\cdot60}$$

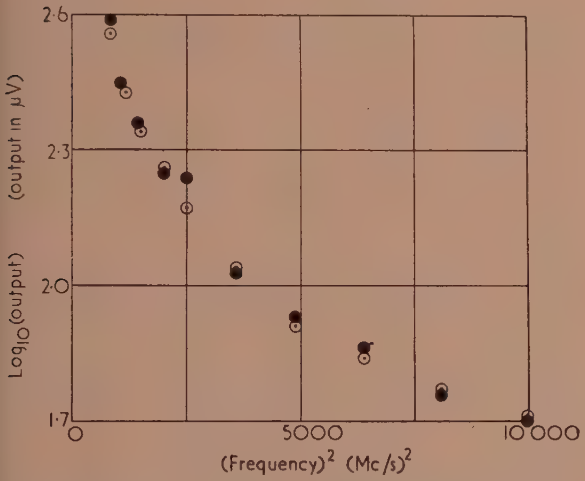


Fig. 2. Plot of log (output) against (frequency)^2 using E.M.I. experimental photomultiplier

As a law of this kind could obviously not hold down to zero frequency, and the measurements themselves, owing to the nature of the available apparatus, only extended from $f = 30$ Mc/s upwards, it was thought that the true law is possibly of the form

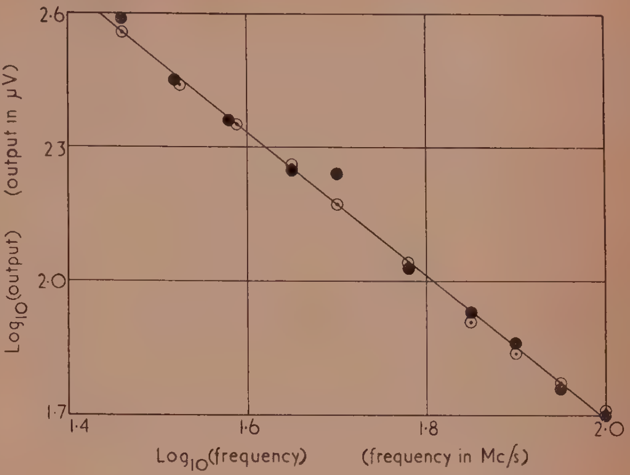


Fig. 3. Plot of log (output) against log (frequency) using E.M.I. experimental photomultiplier

$$(\overline{i^2})^{\frac{1}{2}} \propto |(i2\pi f + \beta)^{-1\cdot60}| = (4\pi^2 f^2 + \beta^2)^{-0\cdot80}$$

which would reduce to the above when $f \gg \beta$, and the Fourier transform⁽³⁾ of which is proportional to $t^{0\cdot60} \exp(-\beta t)$ giving a pulse shape of the same type, having a sharp rise and a slow fall, as that found photographically by Allen and Engelder.⁽²⁾

From the experimental results a value of β could in principle be found by plotting (output)$^{-1/0\cdot80}$ against f^2. However, to do this with any accuracy at all, the measurements described above would have had to be extended to below 30 Mc/s. Once β is known, the duration of the pulse which is determined chiefly by the exponential term would be given in order of magnitude by $1/\beta$, while the time of rise to the maximum would be given by $0\cdot60/\beta$.

There is reason to believe that the pulse in the Mazda multiplier is practically symmetrical, so that the determination of its duration and shape should be much simpler.

ACKNOWLEDGEMENTS

Thanks are due to Mr. G. E. Condliffe, Managing Director, E.M.I. Research Laboratories Ltd., for permission to publish this paper.

REFERENCES

(1) Sard, R. D. *J. Appl. Phys.*, **17**, p. 768 (1946).
(2) Allen, J. S., and Engelder, T. C. *Rev. Sci. Instrum.*, **22**, p. 401 (1951).
(3) Campbell, G., and Foster, R. M. *Fourier Integrals for Practical Applications*, Bell Monograph B-584, Formula No. 524.2 (1931).

A catadioptric camera for ultra-violet spark photography

By J. Dyson, B.A., Associated Electrical Industries Ltd., Aldermaston, Berks

[*Paper first received* 28 *January, and in final form* 2 *March*, 1955]

In order to perform "time-resolved" photography of long sparks on a strip of film placed inside a flywheel rim, an optical system has been devised based on a nearly concentric mirror-pair similar to that used in a conventional reflecting microscope. A field-flattening lens is used together with two lenses to correct the chromatic defects introduced by the field-flattener. The nominal aperture is $f/1\cdot85$ with a focal length of 72 mm.

Simultaneous photographs of the same discharge are shown taken by a $f/4\cdot5$ quartz-rocksalt achromat and the system described above. These show the advantage to be gained by using the above system.

There are many phenomena associated with the development of long sparks which are not directly observable by electrical methods. It is of great benefit to the interpretation of the process if the light emission connected with these phenomena can be observed and, for this reason, the photography of the spark gap during breakdown is of great importance.

The radiation in question is often faint, of short duration and largely lying in the ultra-violet region, so the use of an optical system of large aperture and good transparency is essential. In the particular case to be considered it was desired to perform "time-resolved" photography by projecting the image on to a 35 mm film placed inside the rim of a large, rapidly rotating flywheel. As a result the size of the imaging system was restricted by the proximity of the web of the flywheel.

DESCRIPTION OF THE SYSTEM

In order to be as free as possible from restrictions due to the flywheel web, it was decided to arrange the axis of the main portion of the optical system parallel to the flywheel axis, and to direct the image radially outwards by means of a 45° mirror. This did not involve any increase in the number of reflexions, as this mirror would, in any case, be necessary at some point in the light path to render the object plane accessible. To achieve the necessary wide separation between the image and the larger optical components, a system of two nearly concentric spherical mirrors, resembling a reflecting microscope objective, was used. This system also gave freedom from vignetting for a sufficiently large field. T arrangement of the optical parts is shown in Fig. 1. Such system gives a field which is convex towards the photograph film, and so a concave field-flattening lens of fused silica w used. The distance between the lens and the film was take as about 5·5 mm to allow for the film clips.

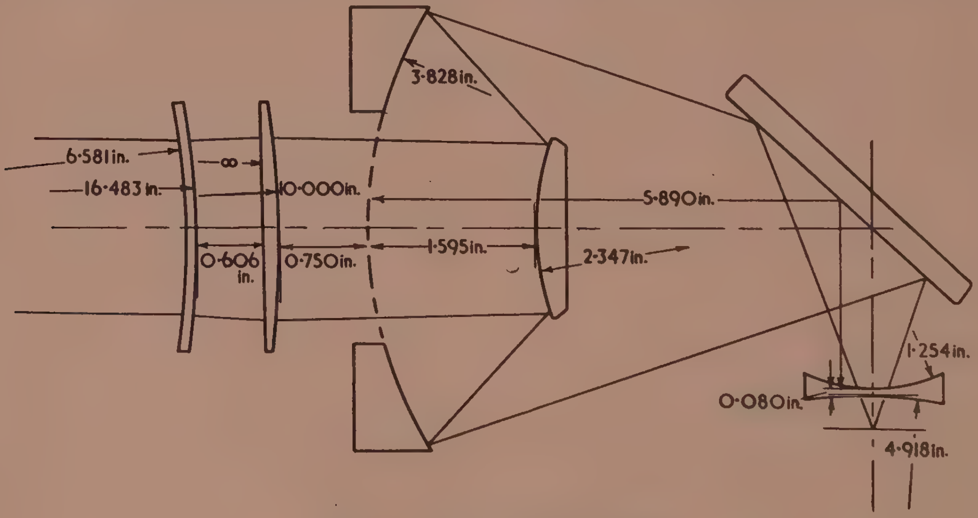


Fig. 1. Layout of optical system

As a result of this rather large distance, the field-flatten introduced chromatic aberration, chromatic difference magnification, and also astigmatism and coma. The chr matic defects were corrected by two weak lenses of fuse silica on the long conjugate side of the system. Coma an astigmatism were controlled by suitably varying the distan between the centres of curvature of the concave and conve mirrors, and also by distributing the total curvature of th field-flattening lens in a suitable manner between its tw surfaces.

This system would normally be used with very fa emulsions of which the resolving power is not very high. addition, the maintenance of focus on the moving film is n an easy matter. Accordingly, a resolution of only 25 lines/mi was aimed at. As this figure is many times worse than tha corresponding to the diffraction limit, the image quality mus be assessed on the basis of geometrical optics alone.

There is no great difficulty in reducing the spherical abe ration to zero, but in fact it was left very slightly positive fo reasons to be stated below.

To maintain the resolution for a total field of 22 mm, th offence against the sine condition had to be kept to a maximu of 0·00060. The value finally attained was 0·00049. Thi

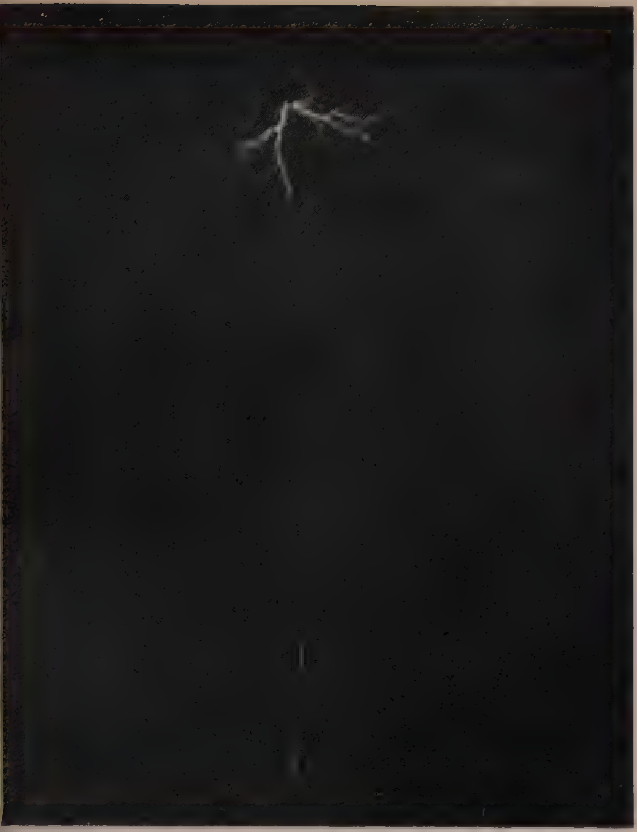


Fig. 2(*a*). Discharge photographed by quartz-rocksalt achromat, $f/4\cdot5$

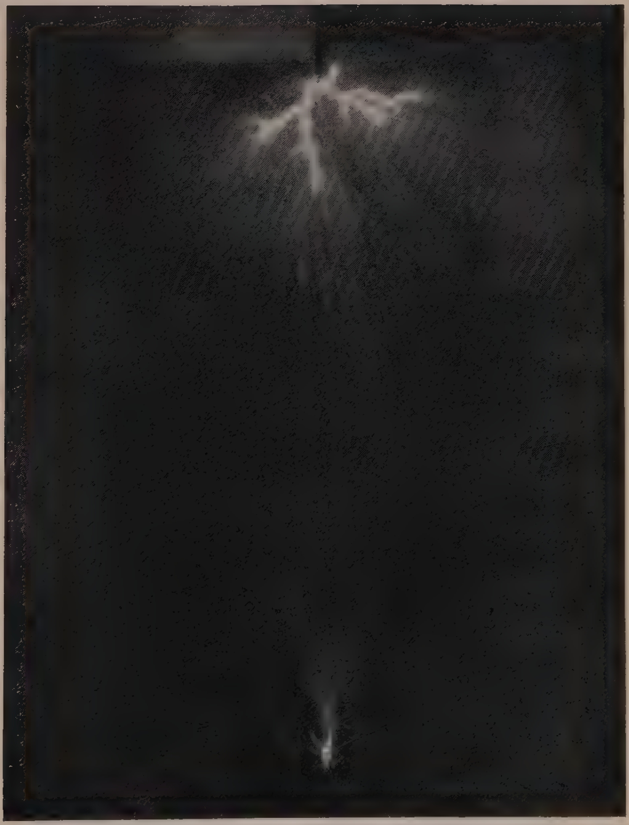


Fig. 2(*b*). Discharge photographed by catadioptric system, $f/1\cdot85$

A versatile absolute rotating cylinder plastometer

By P. Mason, M.Sc., A.Inst.P., and L. M. Smith, B.Sc.

See pages 275–279

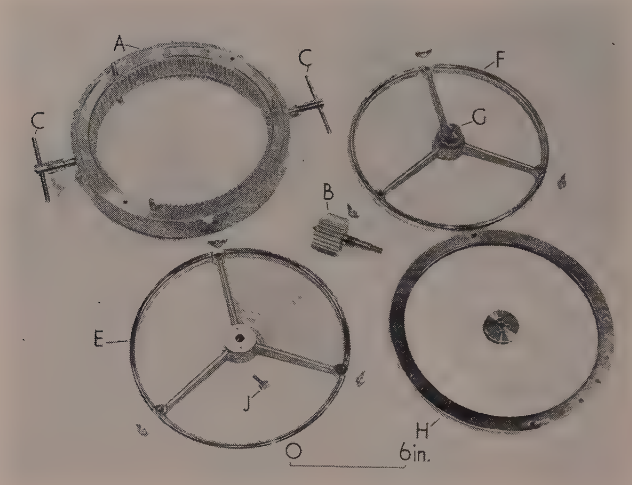
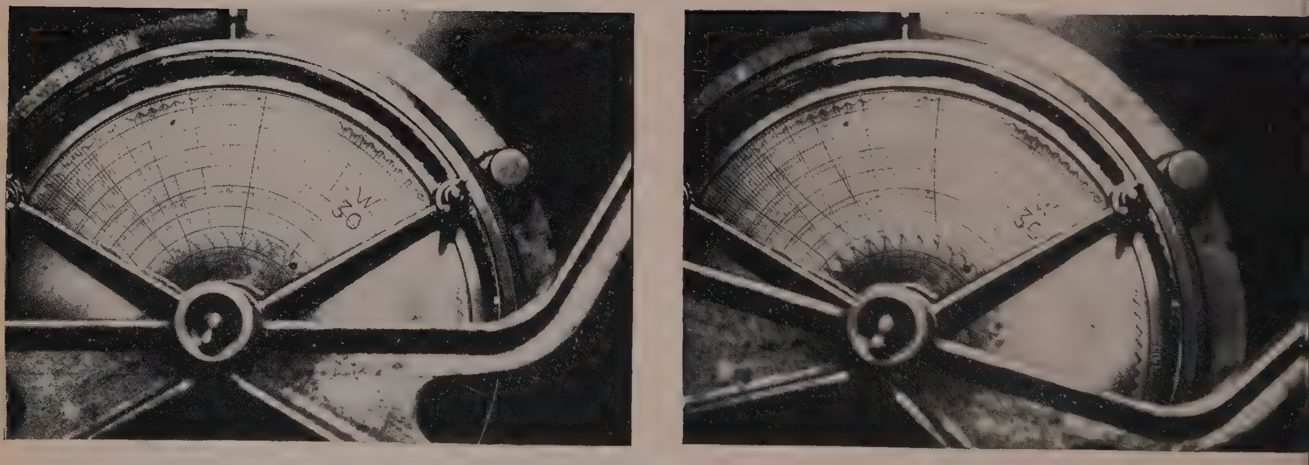


Fig. 2. Principal components of plastometer



(*a*)

(*b*)

Fig. 4. (*a*) Initial view of specimen surface. (*b*) Deformed specimen surface gether with the fact that the light in the coma figure was ongly concentrated towards the paraxial focus, gave a fair rgin in hand.

Astigmatism presented a more difficult problem. The angle incidence of the marginal rays on the more deeply concave rface of the field-flattener reached quite a high value at the ge of the field, so the possibility of relatively large values higher-order astigmatism had to be taken into account. attempt was made to compute this, but the astigmatism e to this surface was left somewhat over-corrected, as it s realized that the astigmatism could be adjusted by eration of the separations. In the event, the higher-order tigmatism was found to be quite small and, accordingly, distance between film and field-flattener was slightly creased to correct the residual astigmatism as far as possible. is adjustment also gave a small change in coma, and, to rrect this, the separation between the concave and convex rrors was altered by the amount calculated to maintain the fence against the sine condition at the maximum given ove.

This adjustment, of course, introduced a small chromatic ference of focus, calculated to be negligible, and a chro- atic difference of magnification. The latter could have en corrected by increasing the separation of the two thin ica lenses, but, as the defect was only a small one, it was t judged worth while to make the necessary alteration to mount. The spherical aberration was made more negative t, as it had been deliberately left slightly positive in the sign, the final result was a satisfactory correction of this erration.

Oblique spherical aberration and higher-order coma had en calculated to be negligible. The final aberrations were, order of decreasing importance, astigmatism, chromatic ference of magnification and coma. The astigmatism uld have been more completely corrected, but the increase chromatic difference of magnification would then have lled for an increase in the separation of the thin lenses: all aberrations together gave a resolution just within 25 lines/mm at the edge of the field, it was decided not to press the correction further.

The focal length of the resulting system was about 72 mm, and a field of roughly 22 mm, or 17·5°, could be attained with only slight vignetting. The aperture of the system was $f/1{\cdot}85$, but about 36% of the area was obscured by the convex mirror. The equivalent aperture may thus be taken as $f/2{\cdot}3$, with a further adjustment for reflectivity of the mirror surfaces. This latter will, of course, vary throughout the spectrum.

RESULTS

Fig. 2 (p. 273) shows still photographs of the same spark. Fig. 2(*a*) is taken with a quartz-rocksalt achromatic doublet, aperture $f/4{\cdot}5$, and Fig. 2(*b*) with the system described above. The discharge was between the electrodes of a rod, gap 42 in. long with a positive impulse of 800 kV "chopped" (i.e. the voltage removed by operation of a subsidiary gap) after 7 μs. The main discharge had not had time to cross the gap completely, and Fig. 2(*a*) would suggest that there is no activity in the centre of the gap. Fig. 2(*b*), however, shows a very extensive system of streamers, some of which traverse the entire gap. These streamers are indicated barely, if at all, on Fig. 2(*a*). This improvement is due to the much heavier exposure attained with the catadioptric system.

The negative used was, in each case, type HP3 plate (by Ilford Ltd.), the processing being identical in the two cases. The photographic grain is more prominent in Fig. 2(*b*), partly because of the increased enlargement as the quartz-rocksalt lens had a longer focal length, and partly because of increased background density due to illumination of the laboratory wall by the spark.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. F. Miranda and Dr. E. H. Cohen for the spark photographs shown herein, and also Dr. T. E. Allibone, Director of the Laboratory, for permission to publish this paper.

A versatile absolute rotating cylinder plastometer

By P. Mason, M.Sc., A.Inst.P., British Rubber Producers' Research Association, Welwyn Garden City, Herts, and
L. M. Smith, B.Sc., British Rubber Development Board, Mark Lane, London, E.C.3

[*Paper received* 23 *December*, 1954]

The construction and method of use of a rotating cylinder plastometer with a wide annulus are described. Absolute shearing stress-strain-time data can be obtained for liquids with viscosities in the range 10^4 to 10^{12} poises as well as for pastes of a wide range of consistency. Continuous loading can be used to produce shearing stresses in the material ranging from about 50 to 5×10^6 dyn/cm^2: transient loading with variable duration and frequency can also be applied from about 10^4 dyn/cm^2 upwards. A stress range of 20 : 1 can be covered in one test. Examples of application to the study of rubber-bitumen systems and asphalts are given.

e most generally suitable instrument for investigating the earing stress-strain-time behaviour of liquids is the rotating linder viscometer of Searle(1) (constant stress) or Couette(2) nstant rate of strain). In this the liquid is sheared in the rrow gap between two cylinders of nearly equal diameter that stress and strain are effectively homogeneous and can adily be deduced from observations of the torque and the tation. This method has been successfully extended to sperse systems, for example paints,(3) macromolecular lutions,(4) and finely divided solid-in-liquid dispersions ch as printing inks(5) and filled bitumens (6) for all of which the narrow gap width was still large compared to the largest dimension of the dispersed phase.

For systems containing relatively coarse particles, such as sand, a wide gap has to be used and the stress is no longer even approximately constant throughout the material. Stress and strain can then be deduced from observations of torque and rotation only if the form of the relation between them is known. This has been done (for example by Lobanov(7) for lime and cement-sand pastes) assuming a Bingham plastic flow relation, but a more general approach was given by Ungar(8) in 1935. Ungar used hemispheres instead of cylinders to avoid end-effect complications, but the essence of his method was to apply a constant torque to the inner hemisphere and to take successive photographs of the deformation of a line initially ruled on the free surface of the material. Values of shearing stress and strain were deduced from each photograph so that the complete shearing stress-strain-time behaviour of the material could be built up.

Ungar's method appears to have been neglected until Ward and Freeman(9) constructed an "absolute concentric cylinder plastometer" operating on the same principle. The materials tested were stiff pastes with yield values of the order of 10^5 dyn/cm^2 and "Bingham viscosities" of the order of 10^7 P, and the use of cylinders enabled the samples to be compacted in position using a ram and a hydraulic press. With cylindrical symmetry the uniform shearing stress τ on any surface in the specimen given by $r =$ constant may be calculated from

$$\tau = M/2\pi r^2 l \qquad (1)$$

where $M =$ applied torque and $l =$ thickness of specimen.

If the observed angular displacement of a point in this surface is θ, the shear strain γ at any instant is

$$\gamma = r\partial\theta/\partial r \qquad (2)$$

The present paper describes an instrument based on that of Ward and Freeman but designed for testing liquids and soft pastes as well as stiff pastes, under steady or transient loading. Applications of the instrument to different materials are given to illustrate the technique of its use.

DESCRIPTION OF THE INSTRUMENT

The main constructional details of the plastometer and its associated equipment can be seen from Figs. 1 to 3 (Fig. 2 on p. 274). Stator A and rotor B provide the cylindrical surfaces between which the test material is sheared. Stator A is 9 in. in internal diameter and is provided with two carrying handles C, which also locate the stator in the levelling stand D and prevent rotation of the instrument as a whole. Two rotors are available, one 2 in. and the other 4 in. in diameter, each provided with a spindle at the top and a conical bearing point at the bottom. Location of the rotor is achieved by the bearings in the upper and lower frames or "spiders" E, which are attached to the rotor by wing nuts so that t instrument can be readily dismantled for cleaning and filli operations.

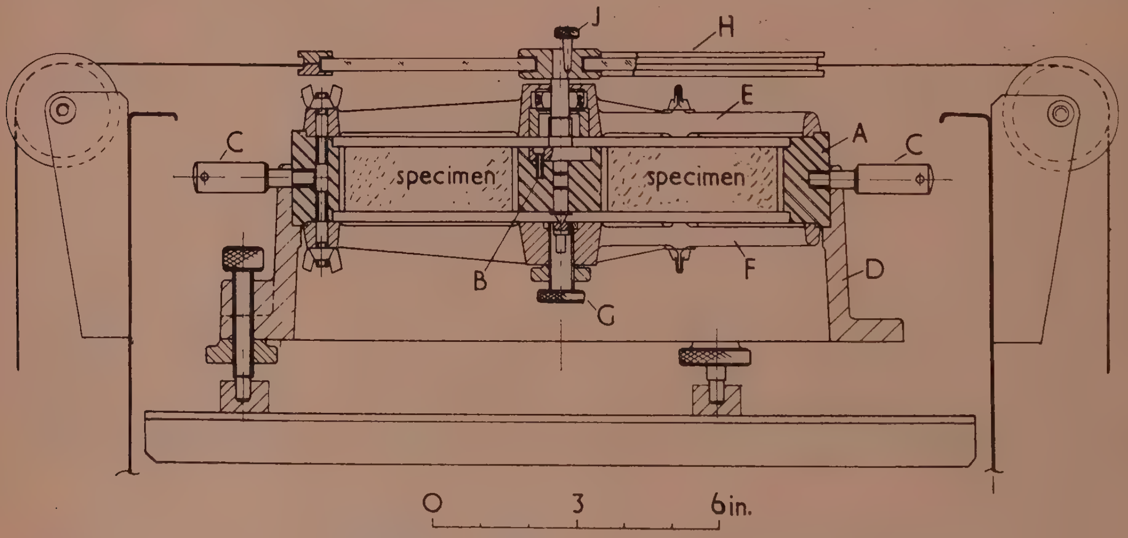


Fig. 1. Sectional view of plastometer in use with steady loading

The lower bearing, in F, is a female conical insert of slight greater cone angle than the rotor bearing point, which c be adjusted in height by the screw G. A universal ball ra (type B.S.I.–BAL 10) housed in spider E provides the beari for the rotor spindle. Measurement of the smallest coup required to turn the rotor with no specimen in positi showed that the torsional friction in this system was less tha 10 g.cm. Between two arms of the upper spider E is fitt a Perspex graticule ruled radially in degrees and circu ferentially at radial steps of 1 cm: this gives a referen co-ordinate system which greatly simplifies the analysis the photographic records.

For steady loading the torque is normally applied to t rotor *via* the 10 in. diameter pulley H. This is made fro toughened $\frac{3}{16}$ in. glass to avoid obstructing the view of t specimen surface, with a brass boss which can be easily key to the rotor spindle by the pin J, and a brass rim grooved take Nylon cord. Loads are applied to the pulley by mea of Nylon cords passing over small pulleys bracketed on t sides of the thermostically controlled water bath into whic the instrument stand fits. For very soft materials the bo alone is used, thus reducing the torque arm by a factor approximately ten. With ordinary laboratory weights the arrangements enable materials to be tested over a range shearing stresses from about 50 to over 5×10^6 dyn/cm^2.

Provision is also made for transient loading, primarily enable the stress-time systems developed under moving traf to be simulated. This has also proved valuable, however, fundamental studies of the mechanical behaviour of t materials investigated, particularly in an examination of t applicability of Boltzmann's principle of superposition.

The arrangement for transient loading is shown in Fig. The pulley is replaced by the aluminium alloy "butterfl which is bounded by circular arcs of 1 ft radius. Two a solenoids are used to apply a balanced load through spindl extended from their plungers and pinned to the rim of t butterfly by finger-tight pins. Holes are drilled at $\frac{1}{4}$ i intervals through both butterfly rims so that the plungers ca lways be kept within a ¼ in. region in the solenoids over which the pull-stroke characteristic is substantially flat. The olenoids are fed in parallel through a Variac and time-witch so that torques of up to 16×10^4 g.cm can be applied ccording to a predetermined programme; a repetitive cycle f 0·5 s at constant stress followed by 20 s at zero stress has ormally been used.

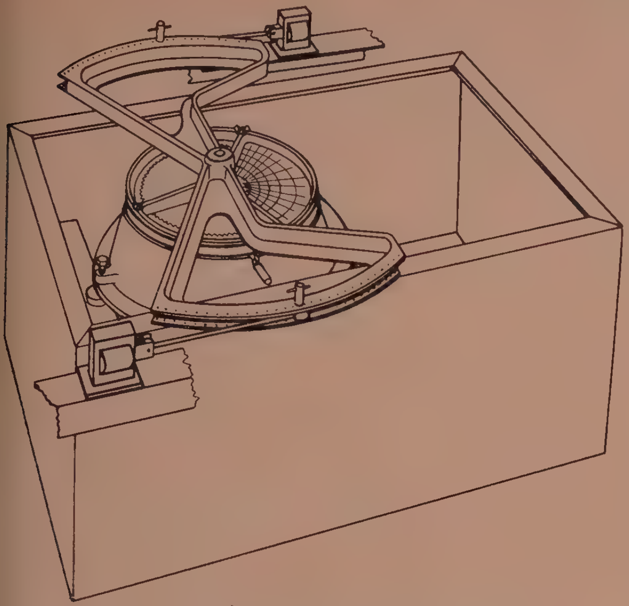


Fig. 3. Plastometer set up for transient loading

METHOD OF USE

The particular technique used in filling and operating the nstrument depends on the nature of the material being ested. Two procedures which have been found useful for ituminous materials are described below.

(i) *For stiff pastes.* Specimens of stiff pastes are prepared the stator using a ram and cover plate in a hydraulic press. his is essentially the technique of Ward and Freeman(9) xcept that for bituminous mixtures the initial handworking f small pellets of material is replaced by heating to about 40° C. As a light-coloured background is required, to show p the graticule, bituminous specimens are sprayed with luminium paint and the lines are marked on the surface ith a needle.

After preparation of the specimen, the instrument is re-ssembled and placed in the testing tank. Specimens which re not affected by water, e.g. bituminous materials or oil-ound pastes, are completely immersed to improve temperaure control and to reduce any tendency to slump under ravity. Water-miscible pastes, of course, cannot be immersed the bath, but fortunately their mechanical properties are enerally much less temperature-sensitive than those of paste ade with organic binders.

This technique is also generally suitable for highly viscous quids such as bitumens or tars with viscosities down to, say, $\times 10^6$ P. It is not necessary to press the specimens which e simply cast in position against the cover plate by pouring hilst hot.

(ii) *For soft pastes and viscous liquids.* In method (i), art from the buoyancy forces acting on submerged specimens, the specimen is supported only at the toothed surfaces of the stator and rotor. Soft pastes and liquids of medium viscosity, say 10^4–10^6 P, clearly cannot be tested in this manner, and provision is made for such materials to be floated on mercury.

A thin stainless steel disk, 10 in. in diameter, is clamped to the lower surface of the stator by means of the lower spider, using a rubber gasket to make a liquid-tight seal. A dimple in the centre of this disk locates the bearing point of the rotor. The upper spider without the graticule is attached and the instrument set up in the test position. Mercury is then run on to the disk until it is on a level with the base of the rotor.

Paste specimens are now prepared by lightly tamping or vibrating the appropriate quantity of paste to fill the gap: liquids can be simply poured into position, after heating, if necessary, to reduce the viscosity for this operation. After marking a suitable line the graticule is re-fitted and the pulley attached ready for testing.

ANALYSIS OF OBSERVATIONS

Each experiment yields a series of photographs of the type shown in Fig. 4(*a*) and (*b*) (p. 274), (*a*) showing the initial condition of the surface and (*b*) the condition after a certain period of loading. A well-marked line in (*a*) is selected for reference, and the angular co-ordinates of its intersections with successive arcs $r_1, r_2 \ldots$ are noted. The corresponding intersections in the subsequent photographs are recorded and by difference the values of θ for each value of r are obtained for each photograph. If the total angular movement of the rotor in the experiment is small, say a few degrees, the analysis is carried out on three separate lines and the results are averaged.

From the set of photographs a family of θ–r curves is plotted and the slopes $(\partial\theta/\partial r)$ of the tangents at different values of r are measured. For each value of r the stress τ is calculated, using equation (1), and the successive values of shear γ using equation (2).

In steady loading tests photographs are taken at suitable intervals to enable strain-time curves to be constructed. In transient loading tests photographs may be taken at any point in the loading-unloading cycle and the scheme adopted will depend largely on the rate at which elastic recovery of the material takes place on unloading. For bitumens and rubber-bitumens it has been found appropriate to take each photograph at ten seconds after an impulse, with intervals of about ten or twenty impulses between photographs. With this procedure there was generally little observable recovery in times of the order of the complete period of transient loading. The observed shear was therefore taken as permanent strain and related to the actual loading time (i.e. the number of impulses multiplied by the impulse duration) to calculate rates of strain and viscosities.

The method of presentation of the stress-strain-time data will, of course, depend on the particular application. For solid systems or purely plastic pastes the stress-strain diagram is generally suitable, whilst for visco-elastic systems a family of shear-time curves corresponding to different stresses is more appropriate. These curves also can be graphically differentiated at any particular value of shear to provide the rate of strain-shearing stress $(D$–$\tau)$ diagram for the material. Ward and Freeman(9) used this method for high polymer solutions containing a high proportion of filler and obtained different $(D$–$\tau)$ diagrams at different values of shear. Their materials were thus characterized by a family of curves which were sections of the $(D$–τ–$\gamma)$ surface at convenient values of γ.

APPLICATIONS

The plastometer has so far been used mainly in an investigation of the influence of rubber on the mechanical properties of bituminous materials. Two widely different examples of this work are quoted below, the first dealing with liquids having viscosities between 10^6 and 10^8 P and the second with granular systems having viscosities of the order of 10^9 P.

At the start of this work comparative tests were made on normal bitumens under constant shearing stress, using both the wide-gap plastometer and the Lee and Warren conicylindrical viscometer,$^{(10)}$ a Searle-type instrument which is widely accepted as a standard viscometer in bitumen and tar research.

Strain-time curves given by the wide-gap instrument were in satisfactory agreement with those obtained with the viscometer, e.g. a maximum absolute difference of about 4% being obtained on comparative tests at 5×10^4 dyn/cm^2 on a "40 penetration" bitumen at 25° C over a range of shear up to 30%.

(i) *Effect of rubber on the viscosity of bitumen.* It is known that if a small proportion of rubber is blended with bitumen by heating and stirring a highly elastic material is produced which is considerably more viscous than the original bitumen. A quantitative study of the viscosity effect was made on a series of bitumens starting with a "60 penetration" bitumen having a viscosity of the order of 10^6 P at 25° C. Rubber-bitumens containing 2, 5 and 10% of rubber were prepared from this by heating with unvulcanized rubber powder for 1 h at 170° C. In addition two other normal bitumens ("40 penetration" and "25 penetration") of higher viscosity were tested.

The behaviour of these materials under transient loading was of particular interest and tests were carried out with a loading cycle of 0·5 s/20 s. After an initial curvature up to not more than 1% strain, the shear increased linearly with time for all materials. It was thus possible to draw rate of shear–shearing stress diagrams applicable to the ranges of shear used (of the order of 40%) and these are shown Fig. 5. These also can be seen to be substantially linear, a the reciprocals of the slopes, i.e. the viscosities, are plot against percentages of rubber in Fig. 6 to demonstrate required relation.

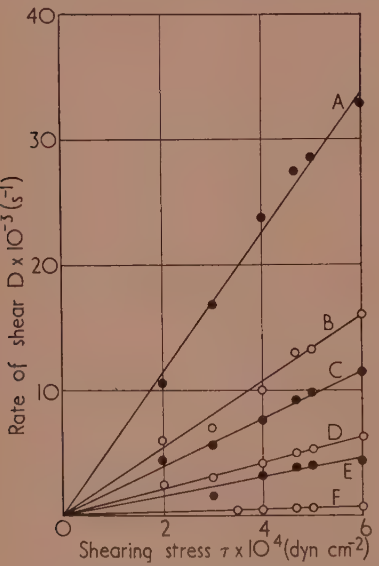


Fig. 5. *D*–*τ* behaviour under transient loading. Temperature = 25° C

Curve *A*, "60 penetration"; curve *B*, "60 penetration" + 2% rubber; curve *C*, "40 penetration"; curve *D*, "60 penetration" + 5% rubber; curve *E*, "25 penetration"; curve *F*, "60 penetration" + 10% rubber.

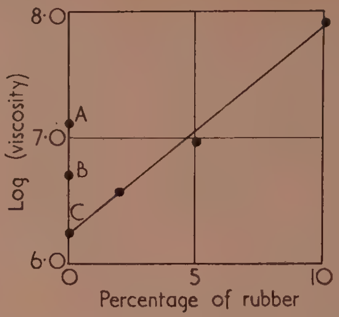


Fig. 6. Effect of rubber on viscosity of "60 penetration" bitumen. Temperature = 25° C

A, "25 penetration"; *B*, "40 penetration"; *C*, "60 penetration.

(ii) *Deformation of asphaltic mixes.* Deformation-ti curves obtained under steady loading on two asphaltic mi are shown in Fig. 7. Mix *A* is a sand-sheet type aspl containing 65·3% by volume of sand, 12·0% finely powde limestone and 22·7% of "60 penetration" bitumen. Mi has the same composition of solid materials but the liq binder is the "60 penetration" bitumen blended with 5% rubber which was examined in example (i).

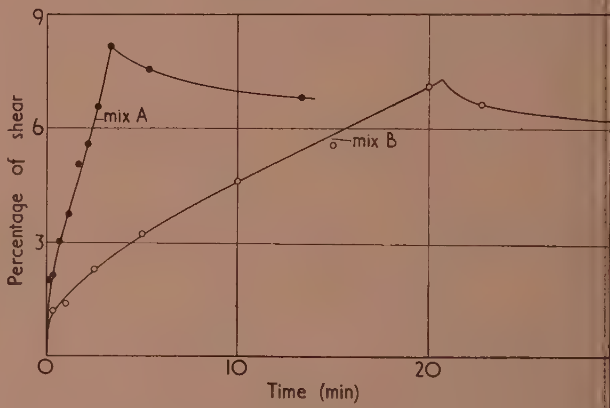


Fig. 7. Deformation of asphaltic mixes under consta shearing stress

Stress = 1·5 × 10^5 dyn/cm. Temperature = 45° C.

Test samples were prepared by pressing at a tempera of 130° C for two minutes under a load of 800 lb Measurements on the samples after test showed that void content was between 10 and 11% for each mate From the linear portion of the curves at about 5% st the viscosities of mixes *A* and *B* can be estimated $4{\cdot}7 \times 10^8$ and $3{\cdot}3 \times 10^9$ P respectively. These values in similar proportion to the viscosities obtained for respective bitumen and rubber-bitumen binders.

ACKNOWLEDGEMENTS

The work described in this paper forms part of a operative investigation undertaken by the Road Rese Laboratory of the Department of Scientific and Indus esearch, the British Rubber Development Board and the itish Rubber Producers' Research Association.

The authors would like to thank Mr. P. R. Freeman, of e Explosives Research and Development Establishment, inistry of Supply, for valuable discussions.

REFERENCES

1) Searle, G. F. C. *Proc. Cambridge Phil. Soc.*, **16**, p. 7 (1912).

2) Couette, J. *Ann. Chim. Phys.*, **21**, p. 433 (1890); *J. Phys.*, **9**, p. 566 (1890).

(3) McMillen, E. L. *Industr. Engng Chem.*, **23**, p. 676 (1931).

(4) Ferry, J. D. *J. Amer. Chem. Soc.*, **64**, p. 1330 (1942).

(5) Buchdahl, R., and Thimm, J. E. *J. Appl. Phys.*, **16**, p. 344 (1945).

(6) Rigden, P. J. *J. Soc. Chem. Ind.*, **66**, p. 299 (1947).

(7) Lobanov, V. P. *Koll. Zhurnal*, **12**, p. 352 (1950).

(8) Ungar, G. *Koll. Z.*, **70**, p. 277 (1935).

(9) Ward, A. G., and Freeman, P. R. *J. Sci. Instrum.*, **25**, p. 387 (1948).

(10) Lee, A. R., and Warren, J. B. *J. Sci. Instrum.*, **17**, p. 63 (1940).

A small pneumatic pyrometer

By A. M. Godridge, B.Sc., Grad.Inst.P., R. Jackson, Ph.D., A.M.I.E.E., F.I.M., F.Inst.P., and
. G. Thurlow, M.Sc., A.M.Inst.F., Grad.I.Mech.E., The British Coal Utilisation Research Association, Leatherhead, Surrey

[*Paper first received* 12 *January, and in final form* 17 *March*, 1955]

The theory of the pneumatic pyrometer, in which gas temperature is determined from density measurements, is outlined and the design and characteristics of a small instrument are reported. Calibration curves covering a wide temperature range (200 to 1550° C) are given and the use of the instrument is described.

1. INTRODUCTION

here is always a need in industry for accurate and robust istruments for measuring gas temperatures, and a variety of ifferent methods and techniques have been proposed or used. mong these, it has been suggested that some temperature ependent property of the gas be measured, and instruments ased on this principle, in which the temperature is found om measurements of gas density, have been developed(1–4) y various workers. This method of temperature measure- ient, termed "pneumatic" pyrometry, has a number of dvantages. In the first place, it avoids the instrument error iherent in direct measurements of gas temperature by, for xample, thermocouples where heat exchange takes place etween the gas and the temperature-sensitive element which annot, therefore, be at the same temperature. An important ractical advantage is that no part of the pneumatic pyrometer as to reach gas temperature and it can be used at temperatures t which many other instruments cannot be successfully used. or example, recent work has shown that the use of suction yrometers on industrial gases above about 1600° C is difficult nd the accuracy hard to evaluate. Another advantage of the neumatic pyrometer is its high rate of response which makes particularly suitable for control purposes. It gives, in ommon with suction pyrometers and other "probe" instru- ients, a local temperature and the temperature distribution cross a gas stream may be found by traversing.

The use of the instrument in flames and other gases where hemical reactions are still in progress has not yet been tudied in detail but, as density is primarily dependent on the ranslational energy of the molecules, the pneumatic pyro- ieter measures a "temperature" closely related to that ontrolling reaction rates and convective heat transfer. This emperature will therefore be more useful in studies of these henomena than that given by other methods based on ieasurement of radiation.

For these reasons the application of a pneumatic pyrometer o the measurement of industrial furnace temperatures has been studied. The present paper is restricted to the work carried out on a rather specialized instrument constructed for a specific gas temperature measuring problem where limited access to the gas led to the construction of a 1 in. outer diameter probe which, in itself, caused problems of design and use.

2. DESCRIPTION OF INSTRUMENT

In the pneumatic pyrometer, two orifices are placed in series, one at each end of a water-cooled probe. A diagrammatic sketch of the layout is shown in Fig. 1. Hot gases enter the instrument through a small heat-resisting steel (Inconel by H. Wiggin and Co. Ltd.) head and pass through the first orifice. The gases are then cooled on passing down the probe before flowing through the second orifice where the temperature of the gas is measured by a thermocouple.

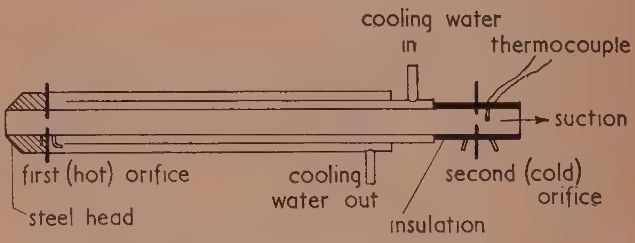


Fig. 1. Schematic diagram of pneumatic pyrometer

The instrument head including the first (hot) orifice is shown in Fig. 2. The main body of the probe is of $\frac{7}{8}$ in. outer diameter steel tube carrying the orifice block, orifice plate and entry head. Within the probe are carried three tubes arranged across a diameter. The central tube, of $\frac{3}{8}$ in. outer diameter, forms the gas suction pipe, while the two outer tubes, of $\frac{3}{16}$ in. outer diameter, are pressure tapping connexions from points upstream and downstream of the orifice. The two passages formed in the annular space by the above arrangement are used for passing cooling water through the probe, connexion between the two spaces being made at the orifice end by means of a groove machined in the central pipe.

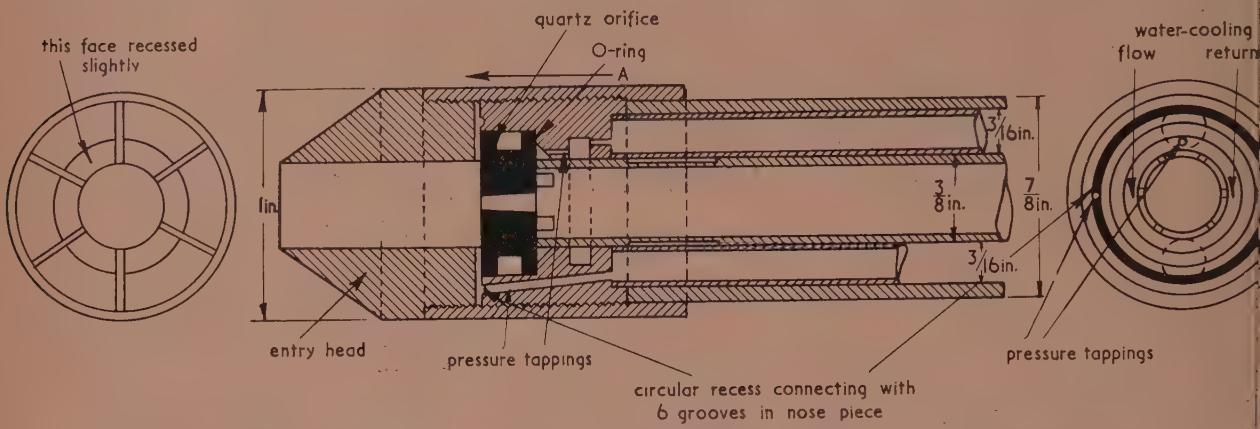


Fig. 2. Detailed drawing of 1 in. pneumatic pyrometer head with end sections in direction of arrow *A*

The orifice plate, made of quartz because of its low coefficient of expansion, is $\frac{5}{8}$ in. in diameter, $\frac{1}{4}$ in. thick and bobbin shaped, the orifice being drilled $\frac{1}{16}$ in. and then ground to a slight taper to give a sharp leading edge to the hole. The disk body rests on the central gas suction pipe and is gripped by screwing down the Inconel entry head. The centre portion of the end face of this head is recessed 0·0005 in. so that the outer region bears on the quartz webs which constitute a spring of limited compression (0·0025 in.). The head may easily be unscrewed for replacement of the quartz orifice plate.

The pressure tappings before the orifice consist of six grooves cut radially in the end of the entry head, connected by a circular groove from which a hole leads through the orifice-containing block to the appropriate pressure pipe. The tappings behind the orifice are six grooves cut in the end of the gas suction pipe where it meets the quartz disk. These are connected by a groove formed by chamfering the adjacent edge of the block. From here the pressure is transmitted *via* a hole to a further groove surrounding the gas suction pipe and then by another hole to the pressure pipe. The series of two holes and a groove was found to be necessary for machining purposes. To ensure a gas-tight joint around the edge of the orifice plate between the upstream and downstream pressure tapping systems, a shallow groove is machined in the orifice block to carry a tin, copper or gold wire O-ring upon which the back web of the orifice plate is pressed by the screwed-on entry head. In the event of high temperatures melting the O-ring, it will still act as a liquid seal held in place by surface tension.

The design of the entry head is a matter for compromise. Too short an entry will result in severely modified gas flow patterns into the orifice if there is a high rate of cross flow past the probe, whereas too long a head will give increased heat transfer from the hot gas to the cooler metal. The present design has a length/internal diameter ratio of about 2 : 1 and experiments up to velocities of about 100 ft/s have shown that, with this ratio, the instrument is unaffected by cross flow.

At the other end of the probe the water leads enter perpendicularly to the body and the pressure leads parallel to the central gas tube. A rubber expansion joint is loc 21 in. from the instrument head.

The second orifice is connected to the water-cooled p by a short ($1\frac{1}{2}$ in.) length of pressure tubing. This or constructed in brass, has a sharp edge diameter of (approximately 2 mm). The overall distance between two orifices is approximately 2 ft 7 in.

The temperature at the cold end of the instrume measured by chromel-alumel thermocouples inserted int gas stream. In the earlier experiments with the instru one thermocouple was located to face "end on" to th stream in a T-junction installed just behind the second o It was found, however, that there was a significant temper drop over the orifice and, in the majority of tests rep here, a second thermocouple was also located befor orifice.

Gas flow through the instrument (0·5 to 1·5 ft^3/min induced by a vane-type blower [by W. Edwards and (London) Ltd.] and the pressure differential across orifice was measured with normal water-filled vertical U gauges. Temperature readings given by the thermoco were recorded in the majority of experiments automat on an electronic instrument (by Honeywell–Brown Lt 3 s intervals.

3. THEORETICAL CONSIDERATIONS

The pressure drop, Δp, across an orifice can be shown energy considerations to be related to flow conditions b formula

$$\Delta p = KM^2/\rho$$

where M = mass flow,
ρ = gas density,
and K is a factor incorporating the characteristics o orifice.

The factor K is dependent on four items: (1) the ph dimensions of the orifice, (2) the entry and exit conditio the orifice, (3) the physical properties of the gas passin orifice, and (4) energy exchanges between the gas an surroundings.

It is possible to keep the influence of the first and l these factors on variations in K small but the influence flow characteristics and gas properties must be allowed f the pressure changes are low, it is possible to assume the physical properties of the fluids are only temper pendent and hence K may be expressed as a function of ss flow and temperature. Hence, a specific gas at a specific ue of mass, pressure drop and absolute pressure over an fice, must be at one unique temperature. It is possible to culate the unknown factors in this expression for the case simple, incompressible hydrodynamic flow and also for ne extensions to this. In the case of the design discussed re, however, it was found that, due primarily to the use of mall orifice ($\frac{1}{10}$ in.), this was difficult. In particular, it was ind by experiment that the straightforward formula for compressible flow could not be applied. The instrument s, therefore, been calibrated directly against temperature d mass flow, assuming from the above that there is a unique ationship for an orifice such that

$$T \propto f(M, \Delta p, P, R) \qquad (2)$$

for simplicity, that:

$$T = (\Delta P/K_1)(P/M^2R) \qquad (3)$$

iere P is the absolute gas pressure upstream of the orifice, is the gas constant and K_1 is a function of temperature and ass flow.

For two orifices in series, the mass flow and gas constant each will, in general, be the same. Designating the orifices suffixes 1 and 2 respectively

$$T_1/T_2 = (\Delta p_1/\Delta p_2)(K_2/K_1)(P_1/P_2) \qquad (4)$$

periment has shown that the maximum pressure drop down e probe is of the order of 3 in. water gauge. Hence, P_1 ay be assumed equal to P_2 within an error of the order of %. As, however, P_1/P_2 is dependent on the mass flow rough the instrument, this error is avoided by writing

$$T_1 = KT_2(\Delta p_1/\Delta p_2) \qquad (5)$$

here K is a factor, to be determined experimentally for any strument at various temperatures and mass flows. Since e instrument cannot be used for making independent mperature measurements its accuracy is limited to that of e instruments used to calibrate it.

The temperature recorded by the pneumatic pyrometer is at related to the density of the gas, i.e. its kinetic properties. he presence of dust in the gas will, in almost all cases, be sufficient to affect the density of the gas, whilst the particles emselves will pass through the orifice too rapidly for anges in their kinetic energy to be effective.

The response of the pressure differentials to a change in mperature is almost instantaneous and changes at the hot ifice affect the cold orifice, at the flow rates used in these sts, in under 0·2 s. The response of the thermocouple at e cold orifice is slower but this has only a secondary effect. he instrument as a whole, therefore, responds very rapidly n less than 0·2 s) to, say, 90–95% of any temperature ange; creeping the last 5% over about 5–10 s, dependent n the magnitude of the fluctuation.

4. CALIBRATION OF THE INSTRUMENT

The instrument was calibrated in a coke-fired down-jet rnace over the temperature range 200 to 1550° C against suction pyrometer of known accuracy.[(5)]

The gas flow through the pneumatic pyrometer was adjusted that the cold air flow reading at the second orifice was etween 1 and 2 in. water gauge, the ratio $\Delta p_1/\Delta p_2$ then eing 4·55. At this particular value, the differential reading r both orifices covered approximately the centre portion of each U-tube gauge, allowing quick and accurate readings to be obtained. The suction pyrometer and the pneumatic pyrometer were then inserted into the furnace at positions such that the instrument heads were located within 2 in. of each other. After each measurement of gas temperature the pneumatic pyrometer was withdrawn from the furnace, allowed to cool and the cold flow reading checked.

A thermocouple located directly in front of the second orifice gave higher temperature readings than the one located behind the orifice (see Fig. 1). This was caused by expansion of the gas at the orifice and heat losses to the cold surroundings. The latter were reduced by insulating the orifice, but for high gas temperatures (1000–1500° C) the difference between the thermocouple readings, which were usually in the range 150 to 200° C, was about 30° C. When calculating K, the average of these two temperatures was used. It is not strictly necessary to do this if K is only to be determined by calibration, as the thermocouple behind the orifice varies almost proportionally to the mean of the two.

The suction pyrometer temperatures were corrected for radiation losses and the thermocouple in the instrument checked at the silver point and found to be reading 2° C low at 960° C. The calibration curve obtained for the pneumatic pyrometer, after applying these corrections, is shown in Fig. 3. The calibration of the pneumatic pyrometer was rechecked after the trials described later (Section 5) over the temperature range 1100 to 1550° C. The agreement shown between both sets of results indicates that the calibration had not changed.

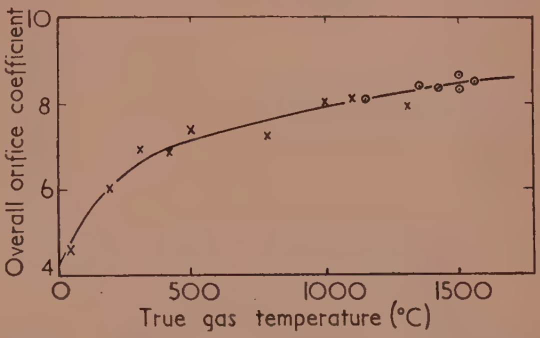


Fig. 3. Calibration curve. $K = (T_1/T_2)(\Delta p_2/\Delta p_1)$

× = calibration before use.
○ = calibration after use.

Assuming the temperature measured with the suction pyrometer to be accurate and bearing in mind the reproducibility of the calibration, especially before and after the tests, an accuracy of ±5% can reasonably be claimed for the pneumatic pyrometer.

5. PRACTICAL USE OF THE INSTRUMENT

The instrument has been used to measure gas temperatures in the water-cooled neck of a commercial down-jet coke burner. This neck had an inside diameter of 14 in. and was directly connected to the section of the furnace holding the fuel bed.

Calculations[(6)] from combustion data had shown that the temperatures here should be about 1400° C at a carbon dioxide content of 12%. Direct measurement with a sheathed thermocouple, however, gave temperatures of about half this value. Measurements were therefore made with the pneumatic pyrometer for a variety of furnace operating conditions.

The instrument was easy to operate and gave no trouble throughout the tests. The results were self-consistent and showed that at the centre of the water-cooled neck, with the air supply damper fully open, the gas temperatures varied between 1310 and 1390° C.

The instrument has also been used to measure temperature in town's gas and pulverized fuel flames. In the case of the former, difficulty was experienced in obtaining consistent pressure readings due to condensation of water from the hot gas on to the cold inner surface of the water-cooled probe. This difficulty was overcome by passing steam through the water-cooling passages. No difficulty with water condensation was experienced in any other tests so far carried out (due to the higher gas temperatures) but dust blockage of both orifice plates was experienced when testing in pulverized coal flames. The only solution for this was to clean the orifices as soon as periodic cold flow checks indicated that blockage had occurred (usually after two to three minutes' continuous use).

6. CONCLUSIONS

An instrument with a very high practical upper temperature limit has been developed and calibrated for use in the temperature range 200 to 1550° C, with an estimated accuracy of ±5%. The temperature range is at present determined by the upper limit of the calibrating unit.

ACKNOWLEDGEMENTS

The instrument was designed in detail and constructe
Messrs. E. L. Mays and L. Stanghon.

The authors would like to thank Mr. E. L. Tinley
Joshua Bigwood and Co. Ltd., for providing the neces
facilities for the work described in Section 5, Mr. G. C
Sharpe for the use of the down-jet furnace, and the Direc
General, British Coal Utilisation Research Association
permission to publish this paper.

REFERENCES

(1) Moore, D. W. *Aero. Engng Rev.*, **7**, p. 30 (1948).
(2) Blackshear, P. L., Jr. *Trans Amer. Soc. Mech. E*
75, p. 51 (1953).
(3) Wildhack, W. A. *Rev. Sci. Instrum.*, **21**, p. 26 (19
(4) Burton, E. J., and Weeks, D. J. *J. Inst. Fuel*, **26**, p
(1953).
(5) Barber, R., Jackson, R., Land, T., and Thurlow, G
J. Inst. Fuel, **27**, p. 408 (1954).
(6) Sharpe, G. C. H. Private communication (1954).

A sine wave generator for very low frequencies

By W. A. Penton, A.M.Brit.I.R.E., Dominion Physical Laboratory, Department of Scientific and Industrial Rese
Lower Hutt, New Zealand

[*Paper first received* 25 *January, and in final form* 18 *March,* 1955]

This report describes an experimental model of a simple form of generator of very low frequencies, using a cell containing an electrolyte in which two probes rotate continuously. As described it covers approximately the range 0·1 to 2·0 c/s with output levels variable between 2·5 and 60 V peak to peak.

A number of methods of generating very low frequencies have been described. Generally, they depend either upon the beating of two higher frequencies, one of which is variable, or upon the direct generation of the wanted frequencies from some form of variable resistance-capacitance oscillator. The first method is necessarily complex because of the very high frequency stability required of the beating oscillators. The second method, though simpler, requires extreme care in design to produce sinusoidal waveforms at frequencies of a cycle or less.

A third possible method might be the use of a sine or cosine type of potentiometer fed from a d.c. source. It could be arranged that continuous rotation of the potentiometer shaft produced an alternating voltage, the frequency of which was a function of shaft rotation speed. Suitable potentiometers are available but expensive, and at moderately-high rotation speeds their life expectancy would probably not be great. The same applies, from experience in this laboratory, to the use of linear potentiometers driven mechanically either by a swash plate or a Scotch yoke to produce a simple harmonic motion. With these devices, wear of moving contacts soon makes replacements necessary and unless much care is taken they may generate a considerable amount of noise.

The instrument to be described uses a variable-speed mechanical drive, with a cell containing an electrolyte, in which two probes are continuously rotated substituted for the sine potentiometer. A pair of slip-rings delivers
alternating voltage from the probes either direct to the
or through a d.c. amplifier as desired.

This method of generating a very low frequency has
probably been used before, although a search of approp
abstracts for the past fifty years has not revealed any me
of it.

GENERAL DESCRIPTION

A photograph of the experimental model (Fig. 1) is al
self-explanatory. A motor (1/60 h.p. universal), the
of which is controllable by means of a Variac, drive
slip-ring disk through a suitable reduction gear-train.
the slip-ring disk are fixed two probes, made of $\frac{1}{8}$ in. dia
silver-plated brass rod, each $2\frac{1}{4}$ in. long and spaced 1
between centres. The probe diameter chosen appears su
for smoothing irregularities in electrolyte potential grad

A glass cell of square cross-section containing an electr
(tap water is quite satisfactory) is placed below the pr
and so elevated that the probes dip about $\frac{1}{8}$ in. int
electrolyte. Two 18 gauge copper sheet electrodes are
at opposite sides for the full width of the cell. Each is
wide and is immersed to a depth of about 2 in. A $4\frac{1}{2}$
battery is connected to the copper electrodes.

Consider the probes so placed that their plane is
parallel to the electrodes, and then rotated continu
through 360°. Initially there is no potential difference bet

e electrodes. When rotation through 180° has taken place, ere is again no potential difference between them. At the ° position there will be a maximum potential difference tween the probes, its amount depending on the geometry f the system. At the 270° position there will be another aximum of the same value as in the 90° position but opposite sign. Hence continuous rotation causes an alternating oltage to appear across the probes, and in theory, with ertain assumptions, that voltage will be sinusoidal.

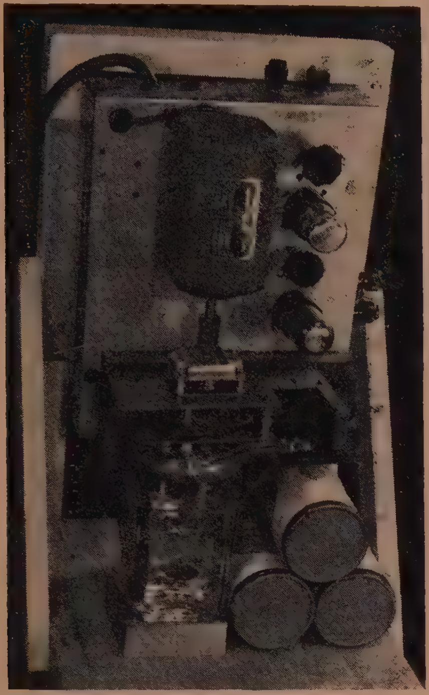


Fig. 1. Experimental model of generator

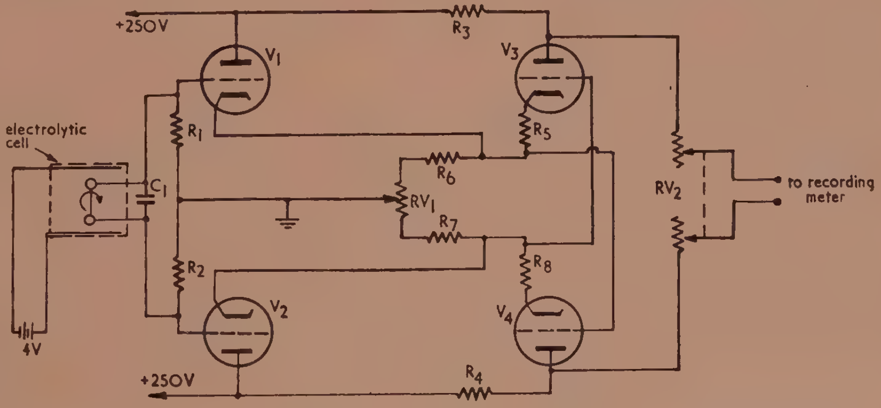


Fig. 2. Circuit of amplifier

R_1, R_2 = 470 kΩ
R_3, R_4 = 82 kΩ
R_5–R_8 = 1·5 kΩ

RV_1 = 1 kΩ wire wound
RV_2 = 50 kΩ wire wound

C_1 = 0·05 μF

V_1, V_2 = ½ 6SN7
V_3, V_4 = ½ 6SL7

The chief of these assumptions is that there is a uniform otential gradient, across the cell. Providing that the probe pacing is less than the width of the cell electrodes, and that e electrolyte itself is homogeneous (a condition that is aided y the stirring action of the rotating probes), this assumption reasonable. Other variables, such as the eccentricity of the robes about their axis of rotation, the actual position of the robe assembly in relation to the electrodes, and the contact otential generated in the probe-electrolyte-electrode system, may displace the average level about which the alternating output voltage swings, but have no apparent effect on its waveform. Typical waveforms at speeds from 0·2 to 1 c/s taken on an Elektronik (by Honeywell–Brown Ltd.) recorder show very little departure from the pure sine wave.

For the purpose for which the instrument has so far been needed, it has been convenient to measure the generated frequency by either a stop-watch or by counting cycles from a recorder of known paper speed. With a suitable motor and reduction gear it would be possible to relate drive voltage applied to the motor directly to probe rotation speed. An a.c. voltmeter measuring the variable supply voltage could then be calibrated directly in cycles per second to a satisfactory repeatable accuracy.

The main shortcoming of the instrument is that it is not portable, the cell having to be drained and refilled if the instrument is moved any distance. In use, the cell gradually precipitates insoluble copper compounds, due to electrolysis, but the performance of the instrument is not affected.

AMPLIFIER AND OUTPUT CIRCUIT

With cell geometry as described the cell resistance is about 1000 Ω and the resistance between probes about 25 000 Ω. 2·5 V peak-to-peak are delivered to a high resistance load. For some purposes this was enough, but in one application about 10 V into a recording voltmeter was required. Hence some amplification was provided.

The circuit used is shown in Fig. 2. V_1 and V_2 are balanced cathode followers. They are fed from the rotating probes, across which is connected a bypass condenser C_1 to remove slip-ring noise. It has no effect on the low-frequency signal component. The cathode-followers drive a "cross-coupled" balanced stage, V_3 and V_4. Balance is reached by adjustment of RV_1 in the cathode chain. Across the anodes of these tubes appears about 60 V peak-to-peak into a 1 MΩ load. The ganged RV_2 are used as a variable series voltmeter resistance to the recording voltmeter. If a current instrument were to be used, appropriate cathode follower output could be added to deliver any current desired. The device under test would normally be inserted between probe output and amplifier input.

CONCLUSION

This experimental instrument has been used successfully in measurements on high-pass filters to cut off below 0·5 c/s. Tests have indicated that its range should be extendible to 5 or 10 c/s before mechanical difficulties become serious.

Laboratory and workshop notes

A uniselector timing unit for controlling scalers

By A. H. WARD, Ph.D., University College of the Gold Coast, West Africa

[*Note first received* 22 *June, and in final form* 22 *September,* 1954]

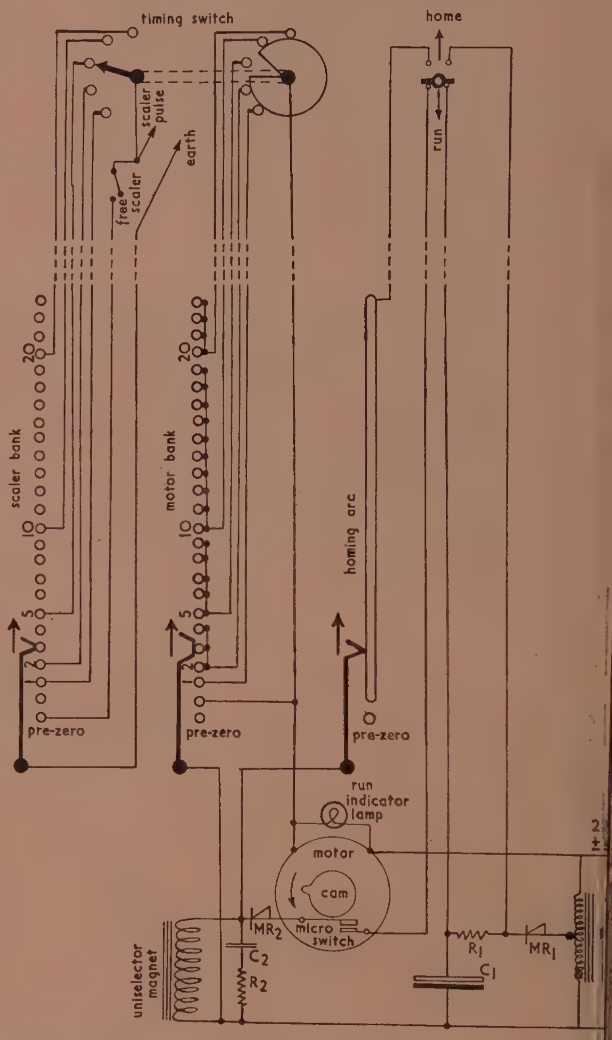
A simple mechanical timing unit has been constructed by which a Dekatron scaler or similar apparatus may be controlled to count for any selected integral number of minutes from 1 to 23. The required time is selected by a rotary switch before or during the timing run, and a simple changeover switch controls the restarting. An accuracy of about ½ sec. in the complete run is attained if a stable frequency mains supply is available. The minimum of components is involved, and no relays or electronic valves are needed.

The circuit consists essentially of a two-bank 25-position 50 V uniselector with homing arc, a two-pole multiway switch to select the desired counting time, and a self-starting, low inertia, synchronous motor geared down to provide one-minute operating pulses. The motor is fitted with a one-point cam and microswitch; the cam should have a steep leading edge for timing accuracy, but otherwise its shape is uncritical. The apparatus is connected as shown in the figure, timing periods of any integral number of minutes from 1 to 23 being pre-selected by soldering from the timing switch to the appropriate contacts on the uniselector.

Before a timing run begins, the wiper arms are in the pre-zero position, the scaler pulses are stopped by the earth connexion through the pre-zero contact on the scaler bank, and the motor is at rest with the microswitch closed. The timing switch is set to the required period and the changeover switch moved to the "run" position; the condenser then discharges through the uniselector magnet, stepping the wiper arms on to the zero position. This starts the scaler and motor, and lights the "run indicator lamp"; the very small magnet current flowing after the discharge is easily stopped by the subsequent opening of the microswitch. The condenser then recharges through the rectifier, and is discharged again when the motor cam closes the microswitch at the end of the complete revolution, thus moving the wiper arms on another step. The cycle repeats, with the motor running continuously, until the wiper arms move to the stop position selected by the timing switch. In the figure the unit is set to run for five minutes. The scaler pulses are then earthed by the connexion on the scaler switch through the scaler bank of the uniselector, thus stopping the count; the synchronous motor is stopped by the open circuit on the motor switch. It should be noted that the uniselector bank for the motor connexions has make-before-break contacts.

The apparatus is stable in this stopped position, but before commencing the next count the changeover switch must be set to the "home" position. This rapidly returns the wiper arms to the pre-zero position by using half-wave current pulses from a small 110 V transformer and rectifier. The motor remains at rest with the microswitch closed. If untimed counting is required, the earth connexion to the scaler is broken by the "free scaler" switch.

Timing errors are found to be almost entirely due to the overrun and initial acceleration of the motor, if the mains frequency is constant; the error is at most ¼ sec. in the first minute period of each counting run. Accuracy could be improved, therefore, by redesigning the circuit so that the motor runs continuously, whether a count is in progress or not; a severe disadvantage of such an arrangement is th delay of up to 1 min will be experienced before the car in position to start a new count. A disadvantage of present circuit is that the motor will be stopped in a ranc position if the "home" switch should be inadverte operated during a timing run.



$R_1 = 6{\cdot}8\ \mathrm{k\Omega}$
$R_2 = 68\ \Omega$

$C_1 = 160\ \mu\mathrm{F}$, 150 V
$C_2 = 8\ \mu\mathrm{F}$

MR_1, MR_2 = metal rectifiers, S.T.C. type k2/10 or equivalent

Uniselector, from General Electri Ltd. or Standard Telephones Cables Ltd. (S.T.C. type 4150).

Motor, self-starting motor type by Everett, Edgcumbe and Co.

Timing switch easily modified standard wafer components.

Spurious counts due to the switching actions in the ci are found to be completely eliminated by the condense and the resistance R_2 across the magnet coil. The uniselec own relay interrupter is not used as it produces severe vo surges.

The timing unit may be used directly on any type of s where the input pulses may be earthed to stop the coun but for other types a subsidiary relay may be necessary will be seen that the circuit which controls the scal electrically isolated from the rest of the timing unit;

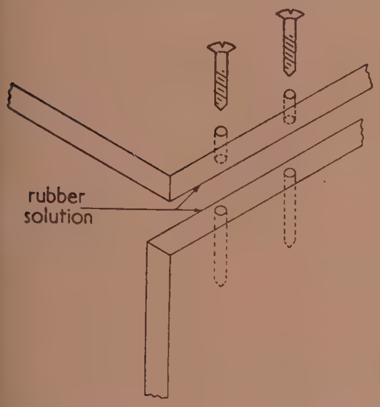
refore possible to control a second scaler from the same ing unit, by bolting a third bank to the uniselector and a rd pole to the timing switch.

A demountable watertight Perspex–Perspex seal

By J. E. Caffyn, B.Sc., F.Inst.P., Physics Department, Durham Colleges in the University of Durham

[*Note received* 28 *January*, 1955]

is well known that Perspex can be joined to Perspex by rious methods, e.g. the surfaces can be wetted with acetic d and pressed together, but with these methods it is tually impossible to separate the surfaces again. A join ich is watertight and which can be repeatedly broken and ormed can be produced in the following way. Two rspex sheets are machined to the requisite shape, butt-nted and screwed together as shown in the figure; this es mechanical strength to the join. To make the join tertight, a uniform thin layer of rubber solution is spread er the surfaces which will come into contact when screwed gether, and when the rubber solution is tacky they are ned. This produces a thin rubber gasket between the rfaces which makes the join watertight.



A butt-ended joint

With the screws removed the pieces can quite easily be parated. If the surfaces in contact are cleaned by wiping th a cloth moistened with benzene they can be again joined above. This can be repeated as often as desired. This thod is not limited to butt-ended joints but can be used other types of joint provided mechanical strength is assured some way.

hollow spindle synchronous motor for use in optical instruments

By D. G. Norton, Division of Physics, National Standards Laboratory, Commonwealth Scientific and Industrial Research Organization, Sydney, Australia

[*Note received* 27 *April*, 1955]

is sometimes necessary in photometric systems to modulate intensity of a beam of light at a fixed frequency. Of the ssible mechanical methods, the rotation of a shutter or a larizing device in the light beam is often the most suitable, d this is best achieved by the use of a hollow spindle nchronous motor. Ideally the spindle should be short and bore large and it is often desirable that the overall size the motor should be small to keep within some specified nensions. A phonic disk motor satisfies these requirements.

For conversion to a hollow spindle motor, a Venner clock motor was chosen for modification. This has a rotor in the form of a hardened steel disk as shown in Fig. 1, with six pairs of permanently magnetized poles around its periphery. The central spindle was removed, a hole ground through the centre of the rotor and a sleeve fitted into it. This sleeve was carried in a very light torque tube precision ball-bearing of large diameter (made by the Fafnir Bearing Co., U.S.A.), the bearing being mounted in a fibre disk attached to the stator. An insulating material was necessary for this mounting to avoid eddy currents. The material of the sleeve is of some importance. If holes of $\frac{5}{8}$ in. or less are required, brass is quite satisfactory; however, if the hole in the rotor is larger than $\frac{5}{8}$ in. a mild steel sleeve is necessary to compensate for the loss of ferromagnetic material. With a mild steel sleeve, a hollow spindle of $\frac{3}{4}$ in. diameter can be used. The adapted motor is shown in Fig. 2; encased, its overall dimensions are $2\frac{3}{4}$ in. in diameter and $1\frac{1}{2}$ in. long.

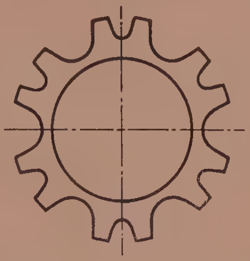


Fig. 1. Rotor with centre moved

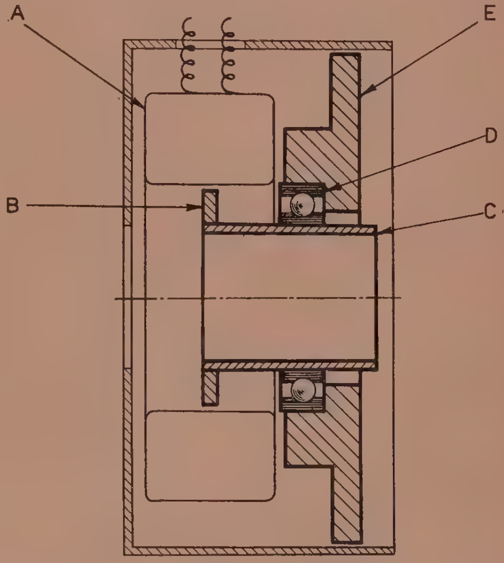


Fig. 2. Section of adapted motor

A, stator and coil winding; *B*, rotor (centre ground to $\frac{3}{4}$ in. diameter); *C*, $\frac{3}{4}$ in. mild steel tube; *D*, light precision ball bearing; *E*, fibre bearing housing.

The stator has thirty pole pieces giving a speed of 200 rev/min or a motor frequency of $3\frac{1}{3}$ c/s with a supply frequency of 50 c/s. As this is rather low for amplification of the signal transmitted, it is desirable to increase the speed of the motor. This can be done by altering the stator or by increasing the driving frequency. It was found advantageous to supply 300 V to the motor. With an oscillator delivering this voltage the supply frequency can be raised to 200 c/s; the current drawn is then 4·8 mA. Above this frequency the motor is unreliable.

NOTES AND NEWS

Correspondence

Analogue computer for a.c. oximetry

An a.c. oximeter, previously described in this *Journal*,[*] requires determination of the ratio of two triode plate currents linearly related to percentage oxygen saturation. The earlier manual method of computation has now been replaced by an analogue computer which consists of a ten-turn potentiometer in the "infrared" cathode circuit driven by a servomotor and amplifier, which maintain a virtually zero potential difference between the moving arm of the potentiometer and a point in the cathode resistance of the "red" circuit. At balance, the position of the moving arm is a linear function of the plate current ratio. The continuous balance system is linked mechanically to another ten-turn potentiometer which acts as a position indicator conveying information electrically through a d.c. amplifier to a recording meter. The scale of saturation is permanently superimposed on the milliampere scale of the ink writing recorder and adjustments for individual earpieces are made at two places only: the potentiometer in the infrared circuit and the variable gain control of the d.c. amplifier.

The instrument, with a time constant somewhat less than 0·5 s, is rapid enough to record changes in oxygen saturation as quickly as they can ordinarily appear in the vascular bed of the pinna. The rapidity of recording and the high available sensitivity and stability with subjects fully oxygenated make it suitable for cardiac output determinations and other cardiovascular studies using Evans blue dye.

Department of Pathological Chemistry, W. PAUL
University of Toronto,
Ontario, Canada.

[*] PAUL, W. *J. Sci. Instrum.*, 30, p. 165 (1953).

Concurrent use of several electrode assemblies with a standard pH meter

Under the above title, Kenchington and Ward[†] described a modification to a standard pH meter which makes it possible to use several glass electrode assemblies for a series of measurements of pH without intermediate restandardization against buffer. It is possible to do this without modification using most makes of pH meters, both direct-reading and potentiometric.

The pH value of a solution in a glass electrode cell is obtained from the e.m.f. E of the latter by using the relation

$$E - E_0 = 0{\cdot}1984 . T . pH$$

where both E and E_0 are in millivolts whilst T is the absolute temperature. For the usual glass–calomel electrode assemblies, E_0 has a negative value which varies with the temperature and, slowly, with time.

With most of the commercially-available pH meters, a p.d. equal to E_0 is placed in series with the cell, when the latter is connected to the input terminals, so that the resultant p.d. across the combination is $E - E_0$ and therefore proportional to pH values. The correct value of E_0 is obtained by filling the cell with a buffer of stated pH value at a given temperature and adjusting the pH meter so that the reading on the meter is the pH value of the buffer, the scale length of the instrument having been made the correct one for t temperature (this is sometimes done automatically by me of a resistance thermometer).

If now the cell is removed and a shorting link placed acr the input terminals, E is made zero and therefore the pH va recorded is given by

$$(pH)_{E=0} = -E_0/0{\cdot}1984T$$

Thus in using several glass electrode assemblies, the meter is standardized for each in turn after which corresponding value of $(pH)_{E=0}$ is obtained.

Before the subsequent use of any assembly, the temperat of which should have remained constant, the input termin are shorted and the standardizing control turned until meter shows the appropriate value of $(pH)_{E=0}$.

All cells should be at the same temperature. If they not, the temperature control of the meter must be brough the correct state for the temperature of each cell before instrument is adjusted to read the appropriate value $(pH)_{E=0}$ when the input is shorted.

The above method also permits a day-to-day check particular electrode.

Department of Physiology, D. M. G. ARMSTRON
Royal Veterinary College,
London, N.W.1.

The construction of two infra-red recording spectro-radiometers

A single-beam recording spectro-radiometer, incorpora the Czerny–Turner(1) optical arrangement, was constru in these laboratories in 1952 and used(2,3,4) for a short ti Provision was made for fitting either Nernst filament or bar sources of radiation and a Hilger–Schwarz type FT thermopile radiation detector was used in conjunction slits 1 cm long, a Gresham 200 : 1 ratio step-up transfor a rotating shutter beam interruptor and an a.c. amplifie conventional design, fixed-tuned to 10 c/s, and of band w 1 c/s. The rectified amplifier output signal was conne *via* a balanced cathode follower circuit so as to operate movement of an Evershed and Vignoles pen recorder. prisms, 60 mm high and 75 mm face, were mounted in su way that they could readily be interchanged with neglig shift in the calibration of the instrument. Littrow scan of the spectrum was effected by means of a microm screw driven by a synchronous electric motor.

A year later, the spectrometer was modified to incorpo Walsh's(5) multiple monochromator concept. Two s plane mirrors were mounted so as to re-cycle the dispe radiation beam and the "chopper" was re-oriented to inter this beam only. Theoretically expected deviation was obse for the sodium D line and the energy dispersion was siderably improved.(6)

A new spectro-radiometer, very similar to the single-b Grubb–Parsons instrument, has now been completed. Grubb–Parsons off-axis paraboloidal collimating m (focal length 20 in.) was used in conjunction with the s prisms, amplifier, pen recorder and spectrum scan mechanism as were used earlier, the latter being impr by the insertion of a four-speed gear box constructed suitable Meccano gear wheels. A Hilger–Schwarz type F ermopile was fitted, together with Hilger slits type F 111 m long and a new voltage stabilizer unit with a gain factor approximately 8 000.

[†] KENCHINGTON, A. W., and WARD, A. G. *J. Sci. Instrum.*, 31, p. 473 (1954).

The spectro-radiometer has shown excellent resolution, om 2 to 20 μ, in several projects(7,8,9) for which it has been ed. The calcium fluoride prism resolves bands spaced by and 2 cm^{-1} in the 3 and 6 μ regions respectively, while sodium chloride prism readily discriminates between nds 5 and 2 cm^{-1} apart at 6 and 10 μ respectively. The tassium bromide prism has proved most satisfactory up 20 μ. Excellent reproduction was obtained and a low ckground energy level was observed for long wavelengths. e gas-tight instrument housing was readily desiccated with osphorus pentoxide and thus interference from water pour bands was negligible.

The authors gratefully acknowledge an equipment grant om the South African Council for Scientific and Industrial search, equipment grants from the Council of the Unirsity of Natal, and a research grant to one of them (A.J.R.) om the South African Mealie Industry Control Board.

epartment of Chemistry, E. C. Leisegang
iversity of Natal, A. J. Rossouw
etermaritzburg, S. Africa.

REFERENCES

Czerny, H., and Turner, A. F. *Z. Phys.*, **61**, p. 792 (1940).
(See also Tetlow, K. S., McAuslan, J., Brimley, K. J., and Price, W. C. *J. Sci. Instrum.*, **28**, p. 161 (1951).
Rossouw, A. J. *M.Sc. Thesis*, University of Natal (March 1953).
Leisegang, E. C. *Ph.D. Thesis*, University of Natal (March 1953).
Barbour, J. B., and Warren, F. L. This work followed the publication by Barbour, Bennett and Warren, *J. Chem. Soc.*, p. 2540 (1951), and a paper has been submitted.
Walsh, A. *Nature [London]*, **167**, p. 810 (1951).
Leisegang, E. C., and Rossouw, A. J. *A Spherical Mirror Double-Pass Monochromator* read to the South African Conference of Physicists, Pretoria, July 1954.
Schüler, B. O. G. *M.Sc. Thesis*. In preparation.
Leisegang, E. C., and Schüler, B. O. G. In preparation.
Rossouw, A. J. *Ph.D. Thesis*. In preparation.

e effect of aluminium purity on the reflectivity of evaporated front surface mirrors

e question is often raised whether the reflectivity of front rface aluminium mirrors is affected by the purity of the uminium volatilized. The need for purity is always stressed, t to our knowledge no comparative data exists on its luence. Two grades of aluminium are readily available, mely, commercial purity (99%) and super purity (99·99%). e former grade may contain as impurities silicon, mannese, iron, copper and zinc, the silicon and iron impurities ing present to the extent of 0·5% or more respectively. nple experiments have been made to ascertain the adverse ect of impurities of this order on the visible reflectivity of aporated aluminium.

Samples of aluminium of commercial purity (99%) and per purity (99·99%) were obtained from Johnson, Matthey d Co. Ltd. Mirrors of the impure and pure grades of uminium were prepared under similar vacuum conditions essure less than 0·1μ of mercury) by arranging two sets glass slides and tungsten heaters inside the vacuum chamber, with vapour shields to prevent metal from one source contaminating the mirror deposited from the other. The reflectivity of optically opaque coatings was measured (1) immediately after removal from the vacuum chamber, and (2) after eight days exposure to the atmosphere when surface oxidation was well advanced.

Measurements of the reflectivity ($R = 100 - A$, where A is the absorption) were made with a photomultiplier tube (type R.C.A. 931A) in combination with Wratten filters (Nos. 50, 74, 21 and 24A). An incandescent tungsten lamp, run from a constant voltage transformer, was the light source and a lens system projected the image of a fine slit on to the mirror surface at an incidence angle of 10°. The wavelength at which the optical system has maximum sensitivity for each of the filter-photocell combinations is given in the table below. The reflectivity could be measured to an accuracy of ±0·5%.

The average reflectivities of mirrors prepared in three separate evaporation cycles were as follows:

Wavelength (Å)	*Reflectivity* (%) *Al* (*purity* 99·99%) (I)	(II)	*Reflectivity* (%) *Al* (*purity* 99%) (I)	(II)
4600	92	89·5	89	86
5300	92	89·5	89	86
5700	93	88·5	90	85
6000	93	88·0	90	86

These results show that the reflectivity is indeed markedly dependent upon the aluminium purity.

Research Laboratories, L. Holland
Edwards (High Vacuum) Ltd., B. J. Williams
Crawley, Sussex.

History of British lampblown scientific glassware

I have been asked by the British Lampblown Scientific Glassware Manufacturers' Association to prepare a history of the British lampblown scientific glassware industry, concentrating in the main on the last 200 years. The industry is, of course, concerned with the manufacture of scientific apparatus by hand but also covers the production of tubular glass containers and other glassware by machinery.

I would much appreciate any help which your readers could give in the provision of information about the history of scientific glassware and the companies within the industry over the last 200 years.

19 Portland Place, D. Rider
London, W.1.

A portable photometer for the testing of reflective road signs

An article of mine was published under the above title in the April 1954 issue of this *Journal.** I have just found that an almost identical instrument was described much earlier by R. Kingslake.† My photometer incorporates a correction filter to make the spectral response of the photocell simulate that of the eye, and a small motor car headlamp bulb instead of the larger 200 W projector lamp used by Kingslake, but apart from these minor differences the two instruments are basically the same.

National Standards Laboratory, R. G. Giovanelli
Commonwealth Scientific and Industrial
Research Organization,
Sydney, Australia.

---

* Giovanelli, R. G. *J. Sci. Instrum.*, **31**, p. 126 (1954).
† Kingslake, R. *J. Opt. Soc. Amer.*, **28**, p. 323 (1938).

Notes and comments

The Institute of Physics

At the Annual General Meeting of The Institute of Physics held on 17 May, 1955, Sir John Cockcroft (Director of the Atomic Energy Research Establishment, Harwell) was re-elected President. Dr. W. H. Taylor was elected a Vice-President, Dr. S. Whitehead was re-elected Honorary Treasurer and Dr. B. P. Dudding was re-elected Honorary Secretary. The three new Ordinary Members of the Board elected were Dr. M. R. Hopkins, Dr. J. M. A. Lenihan and Dr. J. Taylor.

Sir James Chadwick was elected an Honorary Fellow of The Institute of Physics.

The Report for 1954, which was adopted at the meeting, shows that the total membership in the several grades continues to increase steadily and reached 4749 at the end of the year. The newly established Graduate examination was held in London, Birmingham and Paisley, and of the 54 candidates who sat only 19 satisfied the examiners in those papers they were required to take. The number of candidates taking the final examinations for National Certificates in Applied Physics was 206 at the Ordinary level and 75 for the Higher Certificate; these figures compare with 151 and 55 respectively in 1953. The Institute has continued to take an active part in discussions on higher technological education and has not changed the views it expressed in its 1948 Report on this subject. Arising from reports to the Membership Committee indicating that there were several vacancies for undergraduates in departments of physics in some universities and large technical colleges, the Board decided that an inquiry should be made covering the physics departments of all universities in Great Britain and all the colleges recognized by the Institute.

The work involved in the production and distribution of the Institute's publications has continued to increase and now forms about half of the total work of the Institute, the principal part being its monthly Journals, the *Journal of Scientific Instruments* and the *British Journal of Applied Physics* which was established in 1950 and "is rapidly obtaining for itself a place among the leading scientific journals." A third selection of Laboratory and Workshop Notes from this *Journal* was published by Messrs. Edward Arnold (Publishers) Ltd. for the Institute. As with the first two volumes in this series the royalties are credited to the Institute's Benevolent Fund.

The Report states that the day-to-day inquiries on professional matters have included such items as advice on consulting fees and salaries, deferment from military service, appropriate education and training in physics and its special branches and its ancillary subjects, and on sources of technical information. For the second year an inquiry was addressed to all new graduates in physics of universities in the United Kingdom. They were again asked to provide information about their present occupations and, if appropriate, the source of any maintenance grant. There was a good respo
It is proposed to carry out such a survey in each of the
few years and to follow up the returns by making a subsequ
inquiry of those at present engaged on research leading
higher degrees. In this way it should be possible to ob
information that will indicate clearly the way in which
services of physics graduates are being used.

In addition to the several specialist conferences held by
Institute's branches and subject groups, a conference
"The physics of particle size analysis" was held in Nottingh
in April 1954, the proceedings of which were published a
supplement to the *British Journal of Applied Physics*
October. The Report shows that the Institute's sixteen lo
branches and subject groups again held many meetings a
visited various laboratories and works, and in some instan
carried out other functions in connexion with their memb
special interests. Brief reports from the Institute's represen
tives on many outside Committees and Councils conclude
Report of another active year.

Elections to The Institute of Physics

The following elections have been made by the Board
The Institute of Physics:

Fellows: C. F. Bruce, T. J. Buchanan, B. Donovan, J.
Menter, R. Oliver, R. L. Woolley, L. Wright.

Associates: G. R. Antell, S. R. Armsdon, C. Bown
E. J. Burge, L. Cartz, D. A. Davies, J. C. Evans, F.
Fenton, J. Graham, R. C. Gupta, D. O. C. Harker, R.
Harlow, T. E. Heslop, R. C. Holloway, R. H. Hollow
S. Hope, G. Howells, D. Jeffcock, J. T. Johnston, D.
Kahan, D. Macfie, P. M. McGregor, S. C. Nyburg, D.
Payn, A. E. Ranger, E. F. W. Seymour, S. P. Thong, F. C
Tildsley, J. M. Valentine, J. Walters, R. A. Wilson.

Twenty-six graduates, seventeen Students and six S
scribers were also elected.

British Journal of Applied Physics

Contents of the July issue

SPECIAL ARTICLE

Čerenkov radiation and its applications. By J. V. Jelley.

ORIGINAL CONTRIBUTIONS

Time-lag data for spark discharges in uniform field gaps. By A. Aked,
Bruce and D. J. Tedford.
The resistance of the oxide-coated cathode at ultra high frequencies. By
Herbst and J. E. Houldin.
The sedimentation of suspensions of spheres. By R. L. Whitmore.
A general mathematical treatment applicable to certain electrode systems
G. Power.
Electrode shapes for a cylindrical electron beam. By P. N. Daykin.
A germanium point-contact transistor to operate at high ambient tempera
By A. F. Gibson, J. W. Granville and W. Bardsley
The determination of the dynamic properties of crystal diodes. By G. S
Monteith.
Measurement of the pressure distribution between rollers in contact. By
Parish.

NOTES AND NEWS

Correspondence

Thulium 170 for industrial radiography. From K. Lidén and N. St
R. Halmshaw.
Radiation from a hollow cylinder. From M. G. Rossmann.

New books

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principl
construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Squa
London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation*
contributions. (Price 2*s*. 6*d*. including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon applicati
from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, Lond
E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within
days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of addre
or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £4 per volume ($11.50 U.S.A.), including index (post paid) payable
advance. Single parts, so far as available, may be purchased at 8*s*. each ($1.15 U.S.A.), post paid, cash with order. Orders should be sent to The Institute
Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

The physics of clocks and watches*

By J. F. W. Bishop, Ph.D., Mechanical Engineering Research Laboratory, East Kilbride, Glasgow

The mode of operation of the component mechanisms of clocks and watches is reviewed, and the errors in timekeeping which they introduce discussed together with the steps which are taken to rectify them. A review of mechanical clocks includes a consideration of the pendulum and circular, temperature, barometric and escapement errors. Specific escapements are discussed.

Spring, temperature and escapement errors in watches are considered and the methods of compensating for them discussed. A brief account of the marine chronometer and the Shortt clock is followed by the concluding section on the quartz oscillator.

o many physicists the accurate measurement of time is of o greater importance than it is to the scientific layman. his leads to a situation in which time becomes almost a uality. On the one hand is that variety of time by which ne's daily life is regulated and which is commonly five inutes in error depending on the quality of one's watch or hen it was last checked; on the other is the variety of time hich together with length and mass forms the basic dimensions" of mechanics. This variety is (tacitly) taken be resolvable to any desired degree of accuracy. For a few hysicists, amongst whom the astronomers are prominent, he accurate determination of time is of prime importance in heir work. It is therefore not surprising to find that the ontribution of physicists to the science of horology is by no eans unimpressive.

The practical desirability of knowing accurately the standard" time, i.e. the time at some fixed reference point, as brought into sharp focus in the fifteenth century by the roblem of navigation on long ocean voyages. Since an rror of one second in a timepiece corresponds to a positional rror of approximately a quarter of a mile in longitude at e equator, and since voyages of a month without a land x were not unusual, clearly a high standard of timekeeping as required. It is not surprising that with the struggle for a power a major issue of the times, governments should oncern themselves with the problem. It was as the result f a prize offered by the British Government that the first ccessful marine chronometer was constructed.

DESIGN OF A TIMEPIECE

A well-sited and accurately made sundial will record the me to an accuracy of approximately one minute under ptimum conditions. Whilst an inferior mechanical timeiece will certainly have an advantage if the sun is not shining, is accuracy sets a target to be improved upon.

A clock or a watch is an instrument for measuring and cording the passage of time relative to a fixed point in me. The first problem which arises after the construction f a timepiece is the determination of how well the instrument doing its job. For this purpose astronomical observations n selected stars known as "clock" stars are made. Special lescopes called transit telescopes are used to determine the stant at which a clock star crosses the meridian at the bserving station. The position and motion of the clock stars is known with great precision and from them the time of transit can be computed. Thus with an ordinary transit instrument the time can be determined with an accuracy of about ±0·04 s. A refined instrument, the photographic zenith tube gives an accuracy of ±0·009 s. A series of observations enables the time to be determined more accurately. By checking a clock against a series of observations, its rate, i.e. its gaining or losing error, can be found.

The problem in constructing a timepiece is to design a mechanism which will measure off and record equal intervals of time *indefinitely*. This last requirement is very important and poses one of the most difficult problems in horology. Two design criteria suggest themselves to this problem. The first is to design a cycle taking a fixed interval which must be repeated exactly to be free from error. The second is to design a cycle taking a fixed interval in which small variations in the cycle do not affect the interval. Horologists have attempted to design mechanisms of both kinds. Some of the problems arising are discussed in this article. The development is mainly chronological since both the problems and their solutions then fall into natural sequence.

MECHANICAL CLOCKS

Most mechanical timepieces consist essentially of a source of power, a train of gears and a governing device to control the gears to rotate at some fixed rate. The device which is normally employed as a governing mechanism is called an escapement and this is actuated by a regulating mechanism having a fixed period. The earliest mechanical clocks were weight driven. It is difficult to give a date for the first mechanical clock since all timekeepers are embraced under the same term in the records. Mention has been made of a mechanical clock in the year 996, constructed by a monk who later became Pope Silvester II. However, most authorities give the date of the earliest clocks as the begining of the thirteenth century. These early clocks had an inertia type balance consisting of a bar, called a "foliot" mounted at its centre on a vertical axle or "verge." It was rotated first one way and then the other by a toothed escape wheel bearing in turn on projections called "pallets" keyed into the verge. This primitive device was a poor timekeeper, and errors of a quarter of an hour a day were common. The first major scientific contribution to horology was made by Galileo by his observations on the pendulum. It is related that whilst he was at the University of Pisa (1581) he observed that the large hanging lamps in Pisa Cathedral had a period of oscillation which was independent of arc. Whether or not one thinks this is strictly a proper pastime in church, one is bound to admire the acuteness of the observation. It is stated that Gaileo used his pulse to time the swings. It is not recorded what his pulse did when he discovered this important property. Galileo did not construct a clock with a pendulum as a regulator but some authorities believe that his son did so after his death.

---

* Based on a lecture given before the Scottish Branch of The stitute of Physics in February, 1955.

It was Christiaan Huygens (1658) who worked out the theory of the pendulum and who used it in clocks having verge escapements. Huygens showed that the period is not independent of arc for a pendulum having a fixed length. This would only be true if the motion was simple harmonic, i.e. if the restoring force was proportional to the angular displacement. In fact the restoring force is proportional to the sine of the displacement and the period is given by

$$T = \left(2\pi\sqrt{\frac{l}{g}}\right)\left[1 + (\tfrac{1}{2})^2 \sin^2\frac{\alpha}{2} + \left(\frac{1.3}{2.4}\right)^2 \sin^4\frac{\alpha}{2} + \ldots\right]$$

where l is the length of the equivalent simple pendulum, g is the gravitational acceleration and α is the maximum angular displacement from the vertical. Whilst the first term in the bracket is by far the most important for small values of α, it must be borne in mind that an error of one thousandth of one per cent is about one second a day; the second term is therefore by no means negligible for precision timekeeping. The graph in Fig. 1 shows the error in seconds per day as a function of the semi-arc for a pendulum of any length which records the correct time with an infinitesimal swing. This error is known as "circular" error since it is due to the bob moving in a circular arc under gravity. Huygens showed that if the path traversed was a cycloid, then the period would be independent of arc. The method which he suggested for constraining the bob to move in a cycloid was to mount a pair of cycloidal "cheeks" at the point of suspension against which the (perfectly flexible) pendulum rod would bear, thus shortening the rod with increasing arc. Although this is a perfect theoretical solution to the problem of circular error, it has never been put into practice successfully. It will be appreciated that the existence of circular error as such is of no importance so far as timekeeping is concerned; it is only the *variations* in error which matter. Hence, circular error would be satisfactorily accounted for by maintaining constant amplitude. It will appear later how far this object can be achieved.

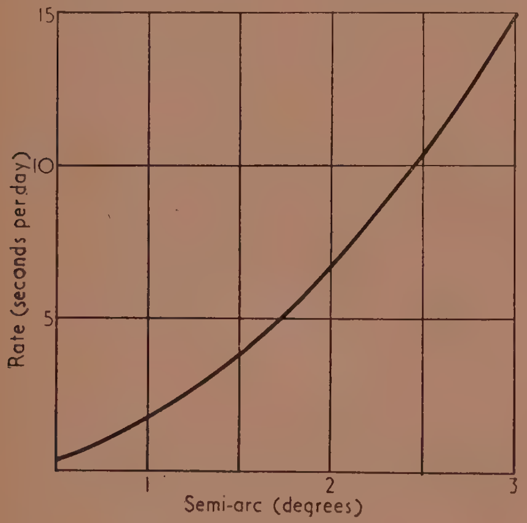


Fig. 1. Circular error

Temperature adjustment. With changes in temperature associated a coefficient of expansion. Since the period o pendulum is directly related to the square root of the len (for a given amplitude), the timekeeping of a pendulum v normally be affected by a change in temperature. In t table the change in daily rate for pendulums of vari materials is given for a one degree Centigrade change temperature. It is seen that the error could be serio

Temperature error

Material	*Change of rate s per day per °C*
Lead	1·2
Zinc	1·1
Brass	0·8
Steel	0·5
Wood	0·1–0·2

This error can be satisfactorily dealt with by using the differ coefficients of expansion of different materials to maint the centre of gravity at a fixed distance below the point suspension. Thus in Graham's compensator, the downwa expansion of an iron pendulum rod is counterbalanced by upwards expansion of the "bob," a jar of mercury. T original compensator was Harrison's "gridiron" pendulu in which iron and brass rods were employed. It is interesti to note that the zinc and iron compensator used in Westminster Clock (Big Ben) has resulted in a quite unlook for secular error. The zinc tube in the compensator undergone "creep" under the load of the 450 lb lead b and adjusting weights have had to be added periodically counteract this effect. An alternative method of temperat compensation was proposed by Guillaume (*c.* 1900). produced a 36% nickel–iron alloy, Invar, which has coefficient of expansion which is nearly zero. The rods precision clocks are normally made of Invar.

Barometric effects. A further variation in the performa of pendulums is attributable to what are known as ba metric effects. The time of swing of a pendulum is invers proportional to the square root of the *effective* gravitatio force, allowance having been made for the buoyancy of atmosphere. Thus there would be a difference of appr mately 7½ s/day between the times recorded by a clock *vacuo* and in the atmosphere due to buoyancy, if it ha steel pendulum. A considerable amount of experime work has been done in the investigation of aerodyna effects on the period of a pendulum. The shape of the b and its density and the presence of the disturbing influe of the case all affect the rate. Added to the buoyancy a aerodynamic effects will be an induced circular error giv the total barometric error. The solution to the probl posed by changes in barometric pressure is obvious. It is enclose the pendulum in a constant pressure (and stri constant density) container. Barometric error is o significant in precision clocks.

Escapement error. A "free" pendulum will gradually to rest due to aerodynamic forces and to frictional a hysteresis losses at the suspension. To maintain its mot momentum must be supplied. This is conventionally kno as impulse and is supplied through the escapement. T eory of the error due to impulsing a cycloidal pendulum is ie to Airy (1827). The following qualitative argument iows how escapement error arises:

In a simple harmonic motion, the time taken to travel from ie vertical position ($\theta = 0$) to a displacement θ is pro- ortional to θ/θ_0 for small angles where θ_0 is the amplitude. ence as the amplitude increases, the time taken decreases. uppose the pendulum is impulsed at the displacement θ_1 in ie direction of motion such that the amplitude is increased om θ_0 to θ_0'. The time actually taken to traverse the arc $= 0$ to $\theta = \theta_1$ was proportional to θ_1/θ_0. However, had ie pendulum completed the whole swing freely with ampli- ide θ_0' this time would have been proportional to θ_1/θ_0', e. a shorter time than actually taken. Hence, since the eriod of a free cycloidal pendulum is independent of mplitude, the impulsing has led to a losing error. This rgument applied to an impulse in the direction of motion *efore* the zero position is reached shows that in those cir- umstances a gaining rate occurs. Hence a uniform impulse iven symmetrically about the zero position leads to a zero scapement error to the first order. Airy suggested a sharp npulse given at the zero position. It will be realized that ie magnitude of the escapement error is unimportant so ong as it remains constant. In the following section a review f clock escapements is made to examine how well they can e expected to function.

Escapements. Escapements for both clocks and watches an be broadly classified into two kinds, friction rest and etached. In the former, the escapement impulses the timing iechanism and then remains in frictional contact with it uring (virtually) the remainder of the cycle, whereas in the tter the timing device is free apart from the interval during hich the impulse is delivered. An example of the former ind is the "anchor" escapement attributed to Robert Hooke Fig. 2). The impulse is being delivered on the pallet A in ie figure by the escape wheel tooth T. When the tooth capes at the tip of the pallet face, the tooth T' will engage i the face B, and for the remainder of the swing in the rection shown the escape wheel is driven backwards for a nall arc. For this reason this is known as a recoil escape- ent. The recoil tends to inhibit large arcs thus tending to ep the amplitude constant and maintaining the circular ror constant. This is responsible for the good timekeeping grandfather clocks, which employ this escapement. A lead-beat" version of this escapement is due to Graham id has pallet faces which are circular arcs with centres at C. this case the escape wheel remains static during the locking riod. In this escapement the impulse is delivered almost mmetrically about the zero position. Graham's escapement is met in precision clocks called regulators, and with attention puts up a good performance. The main sources of error with both of these escapements are the variable friction conditions during the locking period, and the variation in impulse delivered from the train leading to changes in both circular and escapement errors. The detached escapement solves the former difficulty and a device known as a "remontoire" attempts to solve the latter. A remontoire is a mechanism which is "cocked" by the train which is then detached from it. The remontoire then delivers the impulse, which in principle can be kept uniform. The earliest remontoire is due to Mudge (1751) who invented the gravity escapement. In this escapement the impulse is delivered by gravity-actuated arms which are reset by the train and escape wheel. A developed version of this escapement due to Lord Grimthorpe impulses the Westminster Clock and the principle is embodied in two of the precision clocks used today, the Le Roy and the Riefler. Since the impulse is not delivered symmetrically about zero, there is a gaining escapement error which is nearly constant.

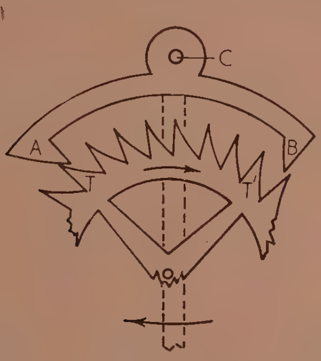


Fig. 2. The anchor escapement

WATCHES

At the same time that mechanical clocks were being perfected, watches were under development. The first watches were made in Nuremberg in the latter part of the fifteenth century. It will appear that nearly all the errors which occur in clocks also occur in watches to a more marked degree. In a watch, the requirement of portability renders the pendulum out of the question as a timing mechanism. The required mechanism is a gravity independent isochronous mechanism, i.e. one having a constant period irrespective of arc. At first sight the spiral spring and balance wheel appear to fill the bill. If a spring obeyed Hooke's law, the restoring couple on the balance wheel would be proportional to the angular displacement and hence the wheel would carry out simple harmonic vibrations. However, real spiral springs do not obey Hooke's law. A spring must be fixed both at the balance wheel axle or "staff" and to a fixed bridge or "cock" in the watch. As the wheel oscillates, the constraint at these pinning points will cause the spring to change shape and its centre of gravity will depart from the line of the staff, thus introducing a gravity component of force. The relative positions at which the spring is pinned to the staff and the balance cock causes an error which changes with the amplitude of swing and with the size of the arc over and above the integral number of turns in the spring (at rest). In Fig. 3 the rate for a spring with an integral number of turns is

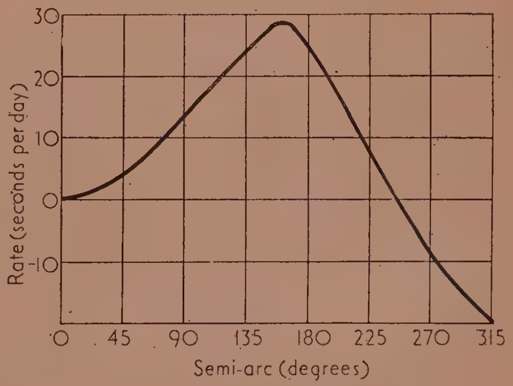


Fig. 3. Spring error

shown as a function of semi-arc. This variation will be mentioned later.

Forms of spring other than the flat spiral are used in watches. One example is the Breguet "overcoil" in which the outer coil is bent up and inwards and pinned near the balance staff. This particular shape enables timing adjustments to be made with reasonable facility.

Temperature error. The effect of alteration of temperature on the period of a balance is not so simple as in the pendulum. The dimensions of both the spring and the wheel change and the modulus of elasticity of the spring varies. Suppose k is the radius of gyration of the balance wheel and that the restoring couple exerted by the spring is $\gamma\theta$ where θ is the angular displacement from rest; γ, the spring constant, will be directly proportional to the breadth b of the strip from which the spring is wound, its Young's modulus E and the cube of the thickness t, and inversely proportional to the length l. Hence

$$\gamma \propto \frac{b.E.t^3}{l}$$

and the period can be simply shown as

$$T \propto \sqrt{\left(\frac{mk^2l}{bEt^3}\right)}$$

where m is the mass of the wheel. Since b and l are similarly affected by the change in temperature,

$$T \propto \sqrt{\left(\frac{mk^2}{Et^3}\right)}$$

If the wheel and the spring have coefficients of expansion of the same order, then it would appear that the period would decrease with rise in temperature. In fact it increases since the fall in Young's modulus swamps the dimensional changes. The spring loss can be of the order of 10 seconds per day per degree Centigrade. There are two satisfactory solutions to this problem. The first is to vary the radius of gyration of the balance wheel, the principle of the cut bimetallic balance wheel in which the balance rim is made of (fused) concentric hoops of steel and brass which causes the rim to curl inwards as the temperature rises (Fig. 4). The second remedy, again due to Guillaume lies in using a spring made of a nickel, chromium, manganese, tungsten steel. This alloy, Elinvar, has virtually no variation of the modulus of elasticity with temperature, and hence the problem is attacked at its source.

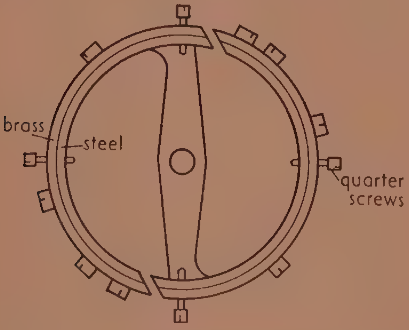


Fig. 4. The cut bimetallic balance

From the expression for T, it can be seen that

$$T \propto k/\sqrt{\gamma}$$

Since T and k are linearly related, approximately, but T a $\sqrt{\gamma}$ are not, complete temperature compensation is normally possible, and a watch can only be rated correc at two arbitrary temperatures. Between these an error kno as middle temperature error occurs. An interesting soluti to this problem was suggested by Guillaume. He produc a 40% nickel–iron alloy which has a non-linear coeffici of expansion. This alloy used in the cut bimetallic bala enables complete temperature compensation to be made.

Escapement error. The theory of watch escapement er is very similar to that outlined in the section on clocks. T most commonly met escapement nowadays is the Swiss le escapement. This is of the detached type. From the desi it would appear that the impulse is given symmetrically ab the zero position, but in fact the inertia of the train proba results in the impulse being given mainly after the z position. Hence the escapement error is a losing one wh can be shown to increase with decreasing arc of oscillati This latter point is important in timing accurate watch When a watch is hanging up, the arc is normally smal than when it is lying on the dial or on its back. This appe to be due to the friction at the pivots. When the watch hanging, the frictional force at the pivots acts over the pi radius, whereas when it is lying the resisting torque is small being the (same) frictional force acting through some m radius of the end of the pivot. Hence in the absence of ot considerations, a hanging watch will have a slower rate (to escapement error) than a lying one. However, it pointed out in the discussion on springs that, with a spiral spring having an integral number of turns, the increased with decreasing arc for an amplitude in the nei bourhood of 200 degrees. This enables the escapement positional errors to be balanced out by suitable springing the watch. It is remarked in passing that if a gravitatio force acts on the balance due to its being out of poise, time-keeping can be badly affected. The simple, approxim solution to this problem is to "poise" the balance by suita weighting the balance by means of the quarter screws in rim. A more complicated remedy lies in mounting the wh balance assembly in a rotating housing driven by the tra thus averaging out the losing and gaining errors due to out-of-poise mass.

THE MARINE CHRONOMETER

It has been mentioned that the need for accurate ti pieces for navigational purposes was an important facto the development of precision timekeepers. The most accu "watch" which has been produced yet is the marine chro meter. This is a large spring-driven, gimbal-mount balance-controlled timepiece with an accuracy of the or of a quarter of a second a day. The balance spring is wo in the form of a helix and the spring drives the train thro a fusee (Fig. 5). When the spring is fully wound the d is through a chain on to the small radius at A. As the sp

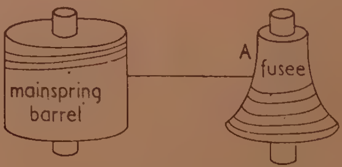


Fig. 5. The fusee

ns down exerting a smaller force, the drive is transmitted an increasingly larger radius to give constant torque. The capement used in the chronometer is peculiar to it, and is e to Earnshaw. It is a detached escapement. It is interest- g to note that the escapement error is swamped by an ror due to the cut bimetallic balance distorting under ntrifugal force thus making the shorter arcs faster than the nger ones. The first successful chronometer was produced Harrison, a Yorkshire carpenter in response to a maximum ize of £20000 offered by the British Government for a nepiece to determine position to better than 30 minutes of c after a voyage to the West Indies. This corresponds to error of 2 minutes in time. The first chronometer which arrison entered for the prize was only 5 seconds in error ter the 6 weeks voyage. He was doubtless more than a tle irritated by the Board of Longitude declining to pay the ize money on the grounds that the performance may have en fortuitous, although finally the whole sum was paid.

THE SHORTT CLOCK

It will have been realized from this article that the nigger the woodpile so far as precision timekeeping is concerned variation of arc, with its associated escapement error and ther spring or circular error. The best observatory clock roduced to date is the Shortt clock which will give a daily ariation of rate of the order of only one-thousandth of a cond over a period of years, with secular changes of only ne or two hundredths of a second. The secret of this excellent erformance lies in giving an impulse only every 30 seconds nd in the use of a master pendulum which swings freely part from the impulse and which does no work; a slave endulum which is synchronized with the master operates a ount wheel and operates repeaters. The clock is shown iagrammatically in Fig. 6. The count wheel C is rotated ooth by tooth by the latch L on the slave pendulum. Every 0 seconds this wheel makes a complete revolution and when e projection P reaches the latch L_s, it releases the gravity rm G_s which impulses the slave pendulum by the roller R_s. he gravity arm continues to fall until it makes contact at $_1$, bringing into operation the electromagnets E_1 and E_2 nd sending a timing pulse to the repeaters. E_1 resets G_s nd E_2 releases the gravity arm G_m, thereby impulsing the master. This arm falls until it completes the contact C_2, activating the magnets E_3 and E_4. The magnet E_3 resets the master gravity arm and E_4 pulls down the spring detent D. At this moment the slave pendulum is swinging to the left. If the spring S on the slave has passed by when the detent operates, the slave pendulum is not affected. If, however, contact is made, an impulse is given to the slave *after* the zero position *against* the direction of motion, inducing a gaining rate. The slave therefore speeds up to get into synchronization with the master. The slave is designed with a slight losing rate to enable this mechanism to operate correctly.

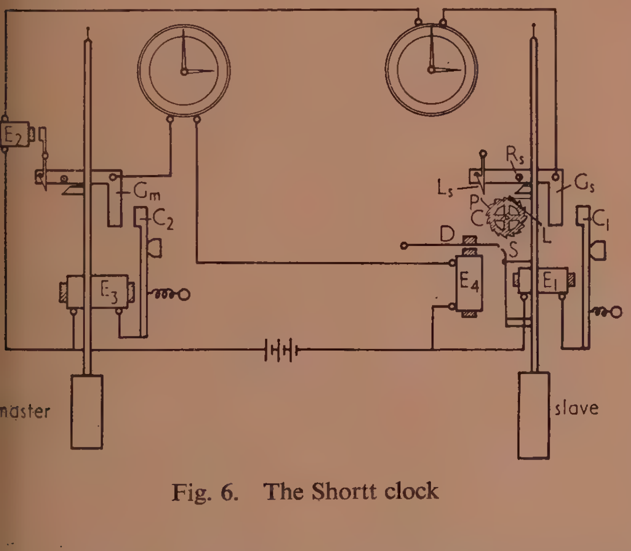


Fig. 6. The Shortt clock

QUARTZ CLOCK

In this article mention has so far been made of only mechanical and electrical clocks. A fairly recent development, the quartz clock, is now sufficiently accurate to give rather better results than the Shortt clock for a period of weeks, but so far has not improved upon its performance over long periods. This clock utilizes the piezo-electric effect. If certain crystals, e.g. Rochelle salt, quartz, are stressed, there is an accompanying charge produced on certain crystal faces. Conversely, if a potential is applied across a piece of the crystal, mechanical deformation occurs. Hence if a piece of crystal is made to vibrate freely, it generates a (decaying) alternating current. The vibrations of the crystal can be maintained by using the generated current to operate a tuned circuit which in turn excites the crystal. Since the frequency of the crystal is a function only of its physical constants, its geometry and the way it is supported, the quartz oscillator is a very stable frequency generator. Normally the oscillations are of the order of 10^5 c/s, and frequency dividers are used to produce a frequency of about 1000 c/s to drive a synchronous motor. The main criticism of this clock lies in that the frequency of the crystal undergoes secular changes over long periods. A clock is under development in the United States which makes use of the vibration of the ammonia molecule as a frequency generator, thus avoiding this difficulty.

CONCLUDING REMARKS

In this article it has only been possible to touch upon some of the applications of science to clocks and watches. Gear design and lubricants, for example, have not even been mentioned. It would not be appropriate in a review article of this kind to quote references in the text, but the author would like to record his particular indebtedness to the publications quoted at the end of the article on which he has drawn heavily. It will be realized that the bulk of the physics contained in this article is of a very homely kind, involving little more than schoolboys are expected to know nowadays. Nevertheless it has been contributed by some of the great physicists of the past, and it is, one would like to feel, a much more typical employment for physics than some of the much more striking and less pleasant applications which have been developed of late.

REFERENCES

(1) RAWLINGS, A. L. *The Science of Clocks and Watches* (London: Sir Isaac Pitman and Sons Ltd., 1948).

(2) WARD, F. A. B. *Time Measurement* (London: H.M. Stationery Office, 1947).

ORIGINAL CONTRIBUTIONS

An optical absorption cell for use at low temperatures

By V. Roberts, B.Sc., A.Inst.P., Radar Research Establishment, Malvern, Worcs.

[*Paper received* 30 *March*, 1955]

A transmission type cell designed for making optical and electrical measurements on solid specimens, but which could be adapted for liquids or gases, is described. The specimen is immersed in helium gas, which provides the thermal connexion between it and the cooling liquid, and can be kept at a temperature within 1° K of that of the cooling bath between about 330° K and 4·2° K. Operating times of over seventeen hours and one hour per filling of liquid hydrogen and liquid helium respectively are obtained. A simple mechanism enables the cooled specimen to be moved into and out of the radiation beam.

Valuable information about the electronic structure of semiconductors can often be deduced from measurements of optical absorption and photoconductivity over a wide temperature range, and there is therefore considerable interest in absorption cells suitable for this purpose.

Two commonly used techniques are the "back reflexion" method in which the specimen rests on a cooled metallic mirror so that the transmitted radiation is reflected back through it, and the "transmission" method in which the intensity of radiation passing through the specimen is measured directly. The first method was usually adopted in order to ensure satisfactory cooling of the specimen, but it has a number of disadvantages; the results are not easy to interpret as the reflected and transmitted intensities are not separable and, since the radiation passes twice through the specimen, the fraction transmitted is correspondingly reduced which is a serious limitation with highly absorbing specimens. The main difficulty with the transmission method has been to provide satisfactory thermal contact between the specimen and the cooling bath. Two techniques have been used in various laboratories; clamping or soldering of the specimen to a cooled copper rod,(1) and immersion of the specimen in cooled helium gas.(2) Of these, the latter is the more satisfactory since the cooling path does not depend on mechanical contact with the specimen and the method can therefore be easily applied to specimens of varying shape, size and chemical composition. Now that a versatile method of window sealing has been evolved,(3) its use presents little difficulty.

The main feature of the absorption cell described below is the specimen chamber, which incorporates gaseous cooling of the specimen and a simple system of mounting, enabling it to be moved out of the radiation beam and accurately repositioned in it while at the operating temperature. The cell is primarily designed for use in a laboratory equipped with a central liquifier (e.g. the Collins helium liquifier) from which the various cryostats are filled by means of transfer vessels. It has now been operating satisfactorily for over a year.

CONSTRUCTIONAL DETAILS OF THE CELL

The construction of the cell is illustrated in Fig. 1. The specimen chamber consists of the copper cylinder *C*, which is hard-soldered into a copper pot *B* (capacity 530 cm^3) containing the cooling liquid, and has suitable windows *W* sealed to its ends by the technique described below. Both *B* and *C* are surrounded by a copper radiation shield *D* which, for operation below nitrogen temperature, is cooled to 78° K by liquid nitrogen in the copper pot *A* (capac
680 cm^3). The radiation shield can be broken at *J* immediat
above the specimen chamber and has two circular apertu
in the radiation path. These apertures can be closed,
cutting off the radiation, by a copper sleeve *G* which
thermally connected to *D* and operated through a bello

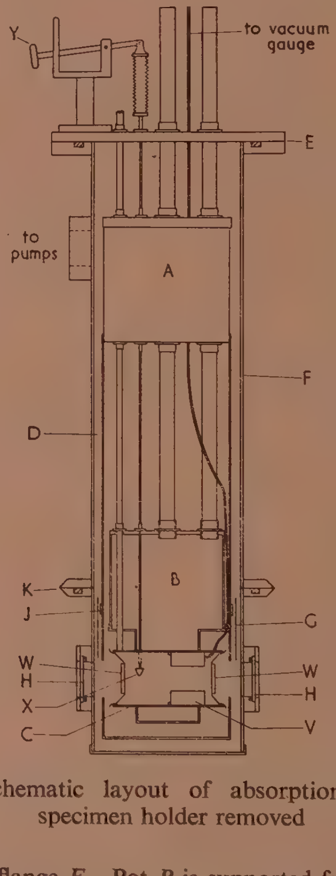


Fig. 1. Schematic layout of absorption cell, wit
specimen holder removed

on the upper flange *E*. Pot *B* is supported from *A* by th
thin-walled cupro-nickel tubes which pass through *A*
act as filling tubes, and the whole assembly is attached to
upper flange *E* by these tubes and three similar tubes lead
to *A*. The main vacuum case *F* can be dismantled at *E*
K and is fitted with suitable windows *H*, normally gl
fluorite, or KRS5. Vacuum-tight seals at *E*, *K* and *H*
obtained by means of O-rings, all the flanges being made
brass. The metal surfaces are highly polished where necess

reduce radiative heat transfer. The length and diameter of e vacuum case are approximately 50 and 13 cm.

Three tubes lead into the specimen chamber, one connects a small gas thermometer which indicates the rate of cooling uring filling and one forms a guide for the specimen holder perating mechanism; the third tube provides a means for vacuating the chamber and filling it with helium gas. lectrical connexions to the specimen may also be led in rough this tube. The gas thermometer bulb, consisting of e annular volume V surrounding the radiation beam, is onnected to a vacuum gauge and filled with helium gas at oom temperature and atmospheric pressure.

The specimen holder (Fig. 2), which is removable from the pecimen chamber for easy mounting and demounting of the amples, consists of a semi-cylindrical shell L which is a liding fit in the specimen chamber (C, Fig. 1). Shell L is orrectly located and fixed in position by a small key M hich fits into a slotted shoulder in the chamber C. The pecimen partly covers an aperture in the plate N which is arried by the leaf springs P soldered to the small posts R. he deflecting arm S passes through a long slot in the leaf pring and is fixed into the plate N at T. A horizontal novement of the other end of S thus moves the plate N across ne holder, the springs being flexed in such a way that the evice returns to the stop Q and accurately repositions the pecimen when the deflecting force is removed. The deflexion applied by a stainless steel cone X (Fig. 1) attached to a ong push rod which passes down the guide tube into the pecimen chamber. This rod, a length of thin-walled cupro-ickel tubing, is sealed in above the upper flange E through ellows and operated by a small lever Y which locks in one f two preset positions corresponding respectively to the pecimen being "in" and "out" of the radiation beam. The vailable specimen movement is about 4 mm. The use of ivots or hinges has been deliberately avoided to reduce the sk of seizure on cooling due to accidental contamination ith a film of grease. Since there is no direct linkage between ne push rod and specimen holder the latter can be withdrawn ith ease. A suitable diaphragm for cutting off radiation cattered round the specimen by irregularities in windows, c., is attached to the gas thermometer immediately in front f the specimen. To facilitate electrical measurements the late N is made of an electrically insulating material such as Tufnol." The specimen is usually held in position by itable light spring clips Z (Fig. 2).

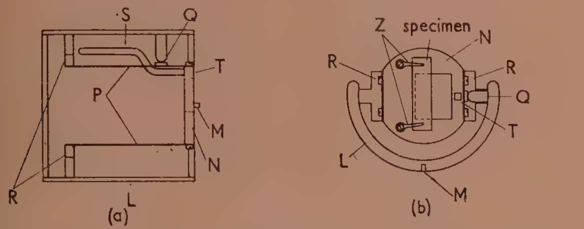


Fig. 2. Specimen holder

(*a*) Plan view. (*b*) Front elevation showing specimen in position.

METHOD OF SEALING WINDOWS TO SPECIMEN CHAMBER

It is clear that suitably transparent windows must be sealed the specimen chamber in a vacuum-tight manner which ill withstand cooling to the operating temperature. The simple technique which has been evolved for this purpose has already been described.(3) Briefly, the window material, in the form of a disk 1 in. in diameter, is fixed to a specially shaped thin copper diaphragm by means of Araldite Type 1 cement. This assembly fits into the end of the specimen chamber and can be soldered in position with Wood's metal. In addition to the materials previously tested,(3) seals made with disks of caesium bromide have now been successfully cooled to 20° K, and will extend the cell's range of operation to about 40 μ. Various of the other materials, e.g. silver chloride, calcium fluoride and glass, are regularly used at hydrogen and helium temperatures and no window seal failures have yet occurred.

METHOD OF EXPERIMENT

The cell is permanently mounted on a Dexion framework in a suitable position above the bench, an arrangement which considerably simplifies operation since the optical alinement, connexions to pumping lines, etc., need not be disturbed for filling purposes. The vacuum case is pumped continuously in use. For spectral measurements, the cell is normally used in conjunction with a Leiss double monochromator,(4) the radiation from the exit slit of which is brought to a focus in the plane of the specimen by a suitable mirror system which effects a slight reduction in the size of the image. The minimum convenient size of specimen is about 10 × 4 mm; a shorter specimen necessitates a reduction in slit length and a corresponding loss of radiation. The transmitted radiation is focused on a suitable detector, normally a thermopile or Golay cell for the infra-red region. Removal of the specimen is effected by breaking the vacuum case at K and the radiation shield at J. The specimen chamber is then accessible, and the window assembly on the specimen side can be removed and the specimen holder withdrawn. Reassembly takes place in the reverse order. Unsoldering of the window seals is easily accomplished by means of a specially-shaped soldering iron which fits into the circumference of the window diaphragm, thereby melting all the Wood's metal together and allowing the seal to be withdrawn. The two parts of the radiation shield are a push fit together and thermal contact may be ensured by applying Wood's metal to the joint. Before cooling, the specimen chamber is filled with clean helium gas at a pressure of a few mm of mercury. For temperatures above 78° K the cooling medium is introduced into the lower pot only; for lower temperatures the upper pot is filled with liquid nitrogen, and the appropriate liquid is syphoned into the lower pot after it has been precooled to 78° K in the case of hydrogen and to a still lower temperature for helium. A metal syphon leading to the bottom pot is permanently built into one of the filling tubes. By cooling at an appropriate rate the variation of conductivity of a specimen with temperature may also be determined, the specimen temperature being measured by a thermocouple.

Although the cell is used chiefly at room temperature and below, operation at higher temperatures, limited by the melting point of Wood's metal (about 330° K), has been possible. This could be extended to near the melting point of soft solder (about 430° K) by using a suitable method of sealing the inner windows.

PERFORMANCE

The rate of evaporation of the cooling liquid, and hence the operating time per filling, is determined by the heat influx to the lower pot. A large part of this is unavoidable radiative transfer through the windows, and most of the remainder is conduction down the filling tubes. The conduction losses can be minimized by making the connecting tubes of material having a low thermal conductivity and arranging for heat exchange to occur between these tubes and the evaporating gas.(5) As the cell is used at present it is convenient to exhaust all the gas through one tube, and measurement shows that the evaporation rate is then 25% greater than if the gas were allowed to flow through all three tubes. Nevertheless under these conditions the operating times obtainable per filling are: nitrogen, over 48 h; hydrogen, over 17 h; helium, approximately $1\frac{1}{4}$ h; the nitrogen in the upper pot being replenished as required (after about 7 h). In practice not more than 1 l. of liquid hydrogen is needed to cool down from 78° K to 20·4° K and fill the cell. Cooling from around 40–50° K to 4·2° K followed by continuous operation at this temperature for up to about three hours is obtained by leaving a 2·5 l. transfer flask of liquid helium connected to the cell and refilling as necessary. It has been verified by direct measurement that the temperature difference between a germanium specimen and the cooling bath was less than 1° K at temperatures down to 20° K and, with the present method of cooling, is unlikely to be greater than this at 4·2° K.(2)

The attenuation of the radiation beam is that due to the four windows and is only about 28% with material of refractive index 1·5 in a spectral region where it is transparent, rising to 70% if the two outer windows are KRS5 and the inner ones silver chloride, a combination which is frequently used. Suitable window materials are available to cover t whole spectral range from the ultra-violet to the far infra-r but for satisfactory work in the far infra-red region t aperture of the cell would have to be increased at the expe of higher evaporation rates and, possibly, a greater tempe ture difference between the specimen and the cooling bath.

The cell has been used for measurements on semiconducto particularly silicon and germanium, some of the results which have already been described in the literature.(6)

ACKNOWLEDGEMENTS

The author is considerably indebted to Mr. A. I. Bria for preparing the detailed design and working drawin to Messrs. J. Cresswell and B. Taylor for their careful c structional work and to his colleagues for many help discussions and suggestions.

REFERENCES

(1) Duerig, W. H., and Mador, I. L. *Rev. Sci. Instru* **23**, p. 421 (1952).
(2) McMahon, H. O., Hainer, R. M., and King, G. *J. Opt. Soc. Amer.*, **39**, p. 786 (1949).
(3) Roberts, V. *J. Sci. Instrum.*, **31**, p. 251 (1954).
(4) Roberts, V. *J. Sci. Instrum.*, **29**, p. 134 (1952).
(5) Wexler, A. *J. Appl. Phys.*, **22**, p. 12 (1951).
(6) Macfarlane, G. G., and Roberts, V. *Phys. Rev.*, p. 1714 (1955).

A simple method of measuring the dynamic Young's modulus of concrete

By J. P. A. Lochner, Ph.D., and W. de V. Keet, M.Sc., National Physical Laboratory, South African Council for Scientific and Industrial Research, Pretoria, South Africa

[*Paper first received* 26 *October*, 1953, *and in final form* 14 *February*, 1955]

The dynamic Young's modulus of elasticity *E* of solids can conveniently be determined from the fundamental transverse frequency of bars. This article describes a very simple device, consisting of a calibrated adjustable Helmholtz resonator, the resonance of which can be observed by means of a stethoscope, for measuring the natural transverse frequency of a rod struck with a small hammer.

It is very often required to measure the Young's modulus of elasticity *E* of solid specimens in order to predict the behaviour of structures of the same material, or else to get an idea of the quality of the material. There is, for instance, a relation between the strength of concrete and its Young's modulus.(1) The quality of concrete specimens can therefore very conveniently be predicted by a non-destructive measurement of Young's modulus.

There are various ways of determining the modulus of elasticity of solids:

(*a*) by loading a sample and measuring the resultant deflexion;
(*b*) by measuring the velocity of sound in the material;
(*c*) by measuring the natural resonant frequency of a sample.

The last method is very often used. The sample usually consists of a bar of known dimensions supported at its nodal points and excited to its fundamental transverse(2) or lo tudinal(3) resonant frequency, which can be accura measured. The bar is usually excited by means of an elect mechanical transducer fed from a variable-freque oscillator. The vibrations are then picked up by a sec transducer, amplified and fed to a valve voltmeter, a maxim deflexion of which indicates resonance. The reson frequency is measured with an electronic frequency meter.

The fundamental resonant frequency of the bar can a be determined by measuring the frequency of an oscilla which has the same rod as its frequency-controll element.(3)

For laboratory work the electronic apparatus was fo satisfactory, but owing to maintenance, power supply a transport problems it was not suitable for field work. The fore a small, non-electronic apparatus was developed an described below. Measurements cannot be taken so rap with this equipment as with the electronic equipment, s simplicity, reliability and low cost makes it very attractive or field work in cases where a limited number of samples ave to be tested at a time.

PRINCIPLE OF OPERATION

A cross-sectional drawing of the equipment developed is hown in Fig. 1. The bar under test is supported at its nodal oints (0·224*l* from the ends, where *l* is the length of the bar) or fundamental transverse vibration. When it is gently truck with a small hammer or rod, it vibrates in its fundamental transverse mode and generates a tone with pitch qual to that of the fundamental transverse frequency. coustic energy from the bar falls on the opening of the Ielmholtz resonator below it, which, when adjusted to esonate at the natural frequency of the bar, will have a naximum sound pressure set up in the cavity. This sound ressure maximum can be observed by means of a stethoscope onnected to it through a probe tube.

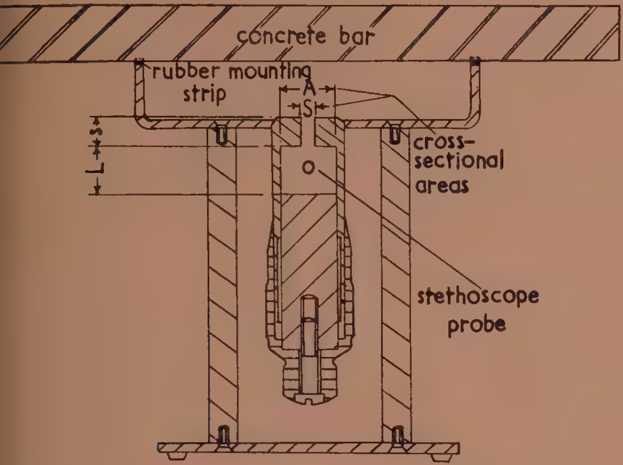


Fig. 1. Cross-sectional diagram of apparatus for measuring dynamic Young's modulus of concrete

Frequency measurements are thus carried out by adjusting he length of the cavity until a maximum signal is obtained hrough the stethoscope when the bar is struck. Readings re taken on the micrometer gauge used for adjusting the olume of the cavity. The present Helmholtz resonator overs the range from approximately 550 to 1700 c/s, which the range for the concrete samples for testing of which it as designed. The dynamic Young's modulus *E* for the naterial can be determined from equation (10).

FORMULAE FOR THE HELMHOLTZ RESONATOR

The resonant frequency *f* of the Helmholtz resonator is iven by(4)

$$f = (C_0/2\pi)\sqrt{[S(1+\alpha_0 t)/ALs]}$$
$$= K_0\sqrt{[(1+\alpha_0 t)/L]} \qquad (1)$$

here $K_0 = (C_0/2\pi)\sqrt{(S/As)}$, C_0 is the velocity of sound in r at 0° C, the factor $1+\alpha_0 t$ corrects it for temperature °C (α_0 has the value 0·003670 as determined by Regnault 1842.(5)) *A* and *L* are the cross-sectional area and length spectively of the cylindrical cavity, *S* and *s* the crossctional area and length respectively of the throat.

CALIBRATION OF THE EQUIPMENT

Relation (1) is an approximate formula and does not take secondary effects, such as the end effects of the neck and non-adiabatic conditions in the cavity, into account. It may be used with a fair degree of accuracy for design purposes, but for actual use of the equipment it is better to obtain an experimental calibration.

With secondary effects included we can assume that the resonator will very closely obey a law of the same form as relation (1), namely

$$f = K\sqrt{[(1+\alpha t)/L]} \qquad (2)$$

Equation (2) may be written as

$$L = (1/f^2)[K^2(1+\alpha t)] \qquad (3)$$

If the temperature is kept constant at a value t_c, the plot of *L versus* $(1/f^2)$ will be a straight line through the origin and will have a slope

$$G_1 = K^2(1+\alpha t_c) \qquad (4)$$

Equation (2) may also be written as

$$L = (K^2\alpha/f^2)t + (K^2/f^2) \qquad (5)$$

If the frequency is kept constant at a value f_c, the plot of *L versus t* will be a straight line intersecting the *L* axis and having a slope

$$G_2 = K^2\alpha/f_c^2 \qquad (6)$$

From equations (4) and (6) we get

$$K = \sqrt{(G_1 - G_2 f_c^2 t_c)}$$

and

$$\alpha = G_2 f_c^2/(G_1 - G_2 f_c^2 t_c)$$

The values of *K* and α were determined as follows for the equipment constructed in this laboratory.

(*a*) The resonator was placed in constant temperature (t_c) surroundings and excited with a pure tone sound field, of which the frequency could be varied over the useful frequency range and accurately measured. The cavity was adjusted to resonance at different frequencies, as indicated by a probe microphone and measuring amplifier, and the micrometer reading *d* was plotted against $1/f^2$, *f* being the resonant frequency. The best straight line was drawn through the points obtained (Fig. 2) and its slope G_1 measured. This straight line,

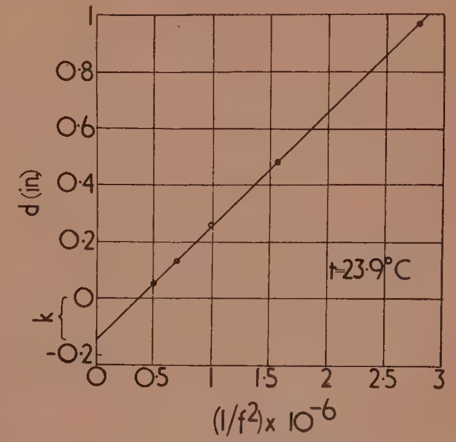


Fig. 2. Curve of micrometer reading (*d*) *versus* the reciprocal of the square of the resonant frequency $(1/f^2)$ of the Helmholtz resonator under constant temperature conditions

when extrapolated, cuts the d axis at a point $d = -k$. This point can be regarded as the point of zero length ($L = 0$) and

$$L = k + d \tag{7}$$

k is thus another constant for the instrument and can be measured from Fig. 2. For the instrument constructed $k = 0{\cdot}15$ micrometer units.

(*b*) The resonator was excited with a constant-frequency pure tone sound field in surroundings where the ambient temperature could be slowly varied and accurately measured. Micrometer readings d were taken at different temperatures t and plotted in Fig. 3. The best straight line was drawn through these points and its slope G_2 obtained.

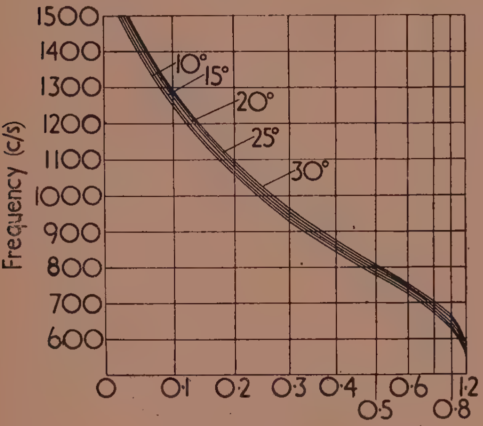


Fig. 3. Curve of micrometer reading (*d*) *versus* ambient temperature (*t*) for the Helmholtz resonator excited at a constant frequency

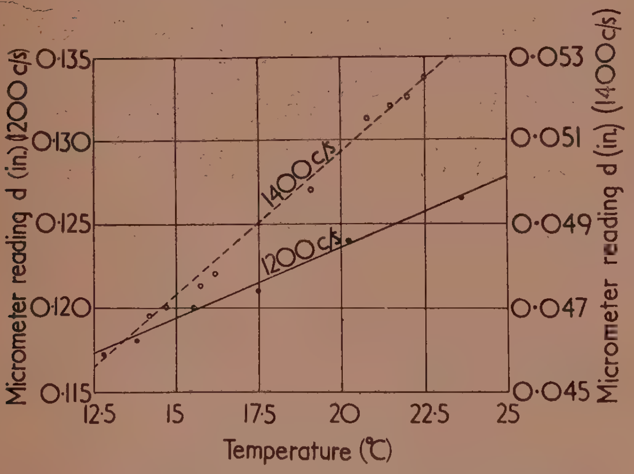


Fig. 4. Calibration curve for the Helmholtz resonator

Thus it was determined that for this particular instrument

$$K = 618 \text{ and } \alpha = 0{\cdot}00327$$

and the resonator frequency f in cycles per second can be determined from the formula

$$f = 618\sqrt{\left[\frac{(1 + 0{\cdot}00327t)}{(0{\cdot}15) + d}\right]} \tag{8}$$

The resonant frequency f can also be determined fr the calibration curves of Fig. 4 which were derived fr relation (8).

For a concrete bar specimen (approximately $2{\cdot}5 \times 2{\cdot}5$ 28 cm in this instrument) of mass W g, length l cm, wi b cm and thickness a cm vibrating in direction a, suppor at nodal points, $E = 0{\cdot}9469\ (Wl^3/ba^3)f^2$ dyn/cm^2 Goens$^{(7)}$ introduced a factor T to correct for the effect slenderness ratio and Poisson's ratio. For this specim $T = 1{\cdot}06$, giving

$$E = 1{\cdot}002(Wl^3/ba^3)\,.\,f^2 \text{ dyn/cm}^2$$

From equations (8) and (9) we get for this instrument

$$E = 3{\cdot}827\,\frac{Wl^3}{ba^3}\left(\frac{1 + 0{\cdot}00327t}{0{\cdot}15 + d}\right) \times 10^5 \text{ dyn/cm}^2 \quad ($$

Equation (10) thus gives a direct relation between Youn modulus E and micrometer reading d at a temperature t.

ACCURACY OF THE INSTRUMENT

The accuracy to which the fundamental transverse f quency of a specimen can be measured depends on:

(*a*) the accuracy to which the instrument is calibrated; a

(*b*) the accuracy to which the resonator can be set to fundamental frequency of the tone emitted when specimen is struck with a small mallet.

From Figs. 2 and 3 it is clear that the calibration poi fall very nearly on a straight line. As all measurements w taken with an indicating meter and frequencies and te peratures could be very accurately measured, it can expected that the accuracy of calibration is very much hig than the accuracy of measurement using the ear as a detec of resonance.

The accuracy to which measurements can be repeated tapping the specimen and adjusting the cavity to resonan as observed through the stethoscope, depends on the sha ness of resonance of the cavity, the sensitivity of the hum ear to variations in intensity and the coarseness of the mic meter thread. The thread used at present is a square c with a pitch of 10 threads per inch, and has virtually backlash. An earlier model had a finer thread but this discarded, since, from the observer's point of view, grea sensitivity is obtained when the resonance point can swept with one continuous finger movement instead of hav to turn the knurled knob through several turns in the reg of resonance.

It is difficult and hardly worthwhile to separate the con butions of these factors to the accuracy. The sharpness resonance of the resonator could, however, conveniently measured and expressed in terms of Q where

$$Q = f/\Delta f$$

f being the resonant frequency and Δf the frequency inte between half power points on the resonance curve. It found that Q varied from 30 at 550 c/s to 20 at 1500 The sharpness of resonance of a resonator depends o number of factors which can be altered by altering the ca and neck dimensions. These factors will, however, no discussed here.

The overall accuracy of the instrument can best be i cated by presenting a number of readings taken on diffe specimens such as is given in the table. Column 2 gives equency readings taken on each concrete bar tested, column 3 ves the average of the six readings and column 4 gives the andard deviation of the six readings. Column 5 gives the sonant frequency of the same bars taken by means of a ore accurate instrument(3) and column 6 gives the per-ntage difference between the results of columns 3 and 5.

From these results it is clear that the accuracy of measure-ent increases with increasing frequency. The standard eviation of measurements is well within ±1% and the bsolute accuracy of the measurements is within ±1% xcept in the case of specimen *A*.

Accuracy of acoustic cavity

Rod No.	*Frequency by acoustic cavity (c/s)*	*Average frequency (c/s)*	*Standard deviation of the mean (%)*	*Frequency by electronic measurement (c/s)*	*Percentage difference*
A	688·5	688·55	0·61	704·6	2·33
	692·6				
	694·7				
	684·5				
	685·3				
	685·7				
B	893·4	894·47	0·44	899·2	0·53
	897·7				
	891·1				
	900·7				
	891·0				
	892·9				
C	1214	1212·7	0·26	1216	0·27
	1214				
	1213				
	1210				
	1217				
	1208				
D	1296	1294·5	0·28	1302	0·57
	1288				
	1298				
	1296				
	1296				
	1293				
E	1339	1340	0·15	1340	0
	1342				
	1342				
	1341				
	1339				
	1337				

CONCLUSIONS

The instrument developed proved to be a very simple, eliable, inexpensive and accurate measuring instrument. lthough it takes more time to operate and is not quite as ccurate as the electronic measuring gear previously deve-ped(3) it has various advantages over the latter.

The instrument needs no power supply and can be used nywhere with convenience. Unlike electronic apparatus, needs no maintenance, which is an important point for eld work.

The instrument can be designed to take a bigger specimen, y 10 × 10 × 50 cm, and used for non-destructive testing of concrete used for structural purposes. When more information regarding the relation between the strength of concrete and its Young's modulus becomes available, it may even be possible to replace the popular crushing tests on cubes by Young's modulus tests with this instrument. It will have the advantage that every concrete consultant can afford to have his own instrument and that the tests can be carried out on the job.

ACKNOWLEDGEMENTS

The authors thank the South African Council for Scientific and Industrial Research for permission to publish this paper.

REFERENCES

(1) Jones, R. *Mag. Concrete Res.*, No. 2, pp. 67–78 (1949).
(2) Obert, L. *Proc. Amer. Soc. Test. Mat.*, **39** (1939).
(3) Stutterheim, N., Lochner, J. P. A., and Burger, J. F. *Mag. Concrete Res.*, **6**, No. 16, pp. 39–46 (1954).
(4) Olson, H. F., and Massa, F. *Applied Acoustics*, p. 25 (London: Constable and Co. Ltd., 1939).
(5) Wood, A. *Acoustics*, p. 245 (New York: Interscience Publishers Inc., 1945).
(6) Wood, A. B. *A Textbook of Sound*, p. 115 (London: G. Bell and Sons, Ltd., 1942).
(7) Goens, E. *Ann. Phys.* [*Leipzig*], **11**, pp. 649–78 (1931).

Low-cost, battery-operated oscillators and detectors for a.c. bridge

By M. D. Armitage, B.Sc., A.Inst.P., South-East Essex Technical College, Dagenham

[*Paper first received* 21 *September*, 1954, *and in final form* 3 *May*, 1955]

From a brief examination of the effects of stray capacitance in a.c. bridge circuits, it is concluded that battery-powered circuits, isolated from earth, can make unnecessary the use of screened, balanced transformers. The relative merits of sub-miniature valves and transistors are considered, the latter being preferred. Adequate performance is obtainable in this way; an oscillator giving 1·0 V in 1000 Ω and an amplifier which will detect 0·01 mV are described, both being powered by dry batteries. A considerable reduction in cost can be achieved by simple methods of construction.

The importance of the a.c. bridge in electrical measurements is unquestioned, but, unfortunately, in the physics laboratories of schools and colleges, the cost of the equipment required (in addition to resistance and capacitance boxes) is such that it is often difficult to do justice to this branch of the subject. Existing equipment can sometimes be adapted to the purpose, but the results thus obtainable do not always show the high accuracy which can be achieved with proper apparatus, and, in addition, such arrangements often involve apparatus which could otherwise be used for other experiments. These considerations led to this attempt to design units giving performance adequate for the teaching laboratory, while avoiding expensive components or constructional methods.

THE PROBLEM AND ITS SOLUTION

An ideal bridge detector would respond only to the potential difference between its input terminals, and would ignore any between either terminal and earth (referred to as unbalanced signals). Furthermore, it would ignore any spurious signals not due to the fundamental component of the bridge output, such as harmonics, noise, etc. In addition, the stray capacitance between either terminal and earth would be small compared to the typical stray capacitances of resistance boxes, etc. Similar arguments apply to the bridge oscillator. Noise, harmonics, etc., may be removed by filtering, but if the oscillator produces unbalanced signals, or the detector responds to them, the null point may be obscured by a "residual" signal, and a false balance may be obtained. The Wagner earth circuit enables these difficulties to be overcome at the expense of some inconvenience, and removes some of the restrictions on oscillator and detector circuits although it would still not be possible, for example, to have one oscillator terminal earthed. When cost is important, however, or when simple experiments are wanted for students who are new to a.c. bridge technique, the Wagner earth circuit is no answer.

The order of magnitude of the residual unbalanced signals to be expected is of obvious interest. A complete analysis, taking into account the strays, is given in Karo's book,(1) but for the present purpose a simple estimate of the effects of an unbalanced potential difference from the source, and of stray capacitance, will suffice. If the detector is to show for a 1% unbalance of the bridge an output ten times the residual, it is necessary (even for a bridge which is easy to balance) that the detector should have a discrimination against unbalanced inputs of the order of 80 dB, and, in addition, for the oscillator to show a ratio of at least 40 dB between balanced and unbalanced outputs. It would appear advantageous, from this point of view, for the amplifier-detector to use a low-impedance input circuit.

Attention must also be paid to impedance matching if maximum power transfer from source to detector is to be obtained. For general purpose equipment, however, it is often good enough to have a moderately-low, oscillator-outp impedance and a moderately-high, detector-input impedan and to tolerate some mismatch in most applications.

ALTERNATIVE TYPES OF CIRCUIT

The necessary performance may easily be obtained by use of screened and balanced transformers to isolate oscillator and detector, and impedance matching can obtained from tappings on the transformers. The tra formers required, however, are very expensive; the co ponents for a mains-operated oscillator and detector u using input and output transformers, would cost £30–£ whereas for the battery type described here the figure wo be about £16.

In considering transformerless detector circuits, the tw triode differential amplifier(2) appears to be a possibility. is not easy, however, to achieve a discrimination greater th about 60 dB owing to the differences between the charact istics of individual valves. The inadequate performance the differential amplifier leads to a consideration of the of single-sided, unbalanced circuits, isolated from earth, a using dry battery supplies so as to keep stray capacitance a minimum. With efficient sub-miniature valves, and tran tors, both needing only small dry batteries, now availa former objections to battery-powered equipment are n largely invalid. An attractive feature for the school or coll laboratory is the small amount of constructional w necessary, as compared to mains-operated equipment.

VALVES OR TRANSISTORS?

If we consider first the design of an amplifier-detector, factors relevant to the choice between valves and transist may be summarized as follows:

(1) voltage gain per stage,
(2) input impedance,
(3) effective mutual conductance of output stage, which required to drive an a.c. milliammeter,
(4) average power consumption per stage,
(5) overall stray capacitance,
(6) total cost.

Typical numerical values of some of these quantities current types of battery sub-miniature valve and transis are given in the table. It is clear that power consumpti mutual conductance, and stray capacitance, give the transis a clear advantage, while the valve has the advantage on in impedance. For cost, the choice is not so clear.

The cost per stage is higher for transistors, but whereas th transistors will give sufficient gain, four valves are neede

In the case of the oscillator circuit, the choice is m difficult. If it is assumed that a frequency of about 1000 *mparative performance of sub-miniature valves and junction transistors in amplifier-detector circuits*

	Voltage gain (ratio)	*Input impedance* (Ω)	*Effective mutual conductance* (mA/V)	*Power consumption* (mW)
lve	30–40	high	1·0	50
ansistor	30–40	1800	50	5

required, and that a resistance-capacitance circuit is to be ed for cheapness, convenience and reduction of size, the cillator will consist of an amplifier, a feedback network d an output stage. Stability of frequency is unimportant, d a small amount of harmonic distortion can usually be erated, but it is essential that loading of the output by pedances down to 1000 Ω, or rather less, should not unduly ect the amplitude of oscillation, or the waveform. The tput required may be quite small, a few volts in 1000 Ω ing sufficient. It is possible to make a single-stage, sistance-capacitance oscillator with a valve, but it seems at two transistor stages are needed, to allow the use of network with low output impedance. The necessary tput power can easily be obtained from a valve, and a low ough output impedance by the use of feedback, but to ovide even 1 V r.m.s. in 1000 Ω needs either a steady ode current of 4–5 mA or a step-down transformer. A nsformer would thus be essential with battery sub-miniature lves, but a junction transistor can easily carry the necessary rrent. (British types now available will dissipate 200 mW d carry 20 mA, making possible an output of several volts n.s.) The transistor also has the advantage on the score of wer consumption and, hence, battery stray capacitance.

TWO TRANSISTOR CIRCUITS

The circuit adopted for an amplifier detector is shown in g. 1; it may be treated as three stages of current amplifica- on, of which the third works into a low-impedance load esented by the rectifier and milliammeter. The transistors e operated in the common emitter configuration, which es optimum results for most purposes.(3) The use of nsformer rather than *R–C* coupling allows some reduction of battery voltage, and an increase of gain, for some increase in first cost. The resistors R_1, R_4, R_5 provide bias current to the transistors; some measure of stabilization against falling battery voltage and changes in transistor characteristics is given by taking the bias from the collector rather than from the negative supply rail. A very simple method of gain control is provided by R_3. The output stage is designed to give maximum gain for small signals, and to overload before full-scale deflexion of the meter is reached. The performance of the circuit of Fig. 1 can be summarized as follows:

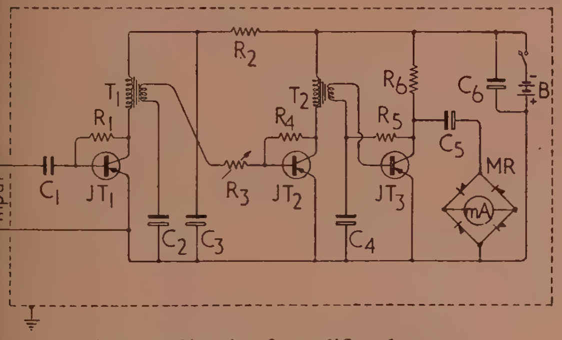


Fig. 1. Circuit of amplifier-detector

R_1 = 68 kΩ
R_2 = 4·7 kΩ
R_3 = 100 kΩ
R_4 = 68 kΩ
R_5 = 68 kΩ
R_6 = 3·9 kΩ

B = 2·6/3 V dry battery

MR = instrument rectifier
mA = 0·5 mA instrument

JT_1, JT_2 = Mullard type OC70
JT_3 = Mullard type OC71

C_1 = 1 μF, paper
C_2 = 8 μF, electrolytic
C_3 = 8 μF, electrolytic
C_4 = 8 μF, electrolytic
C_5 = 8 μF, electrolytic
C_6 = 50 μF, electrolytic

T_1, T_2 = Multitone type T100

all resistors 1/10 W, 10% tolerance
all capacitors low-voltage types, 20% tolerance

Gain: When $R_3 = 0$, an input of 10 μV at 1 kc/s gives a detectable output (0·01 mA).

Discrimination against unbalanced signals: more than 100 dB.

Range of gain control: 60 dB.

Capacitance to earth: 80 pF (in earthed metal box 6 × 6 × 3 in.).

Battery consumption: 1·5 mA at 2·6 V.

The circuit of a 1 kc/s oscillator is shown in Fig. 2; here the stages are *R–C* coupled, bias being provided by the pairs of resistors such as R_1 and R_2 and stabilization by the resistors in the emitter circuits. The oscillation frequency is determined by a low-impedance network of the Wien bridge type; the frequency stability is not good, due mainly to the effect of the input impedance of JT_1, which is still relatively low in spite of the feedback in the emitter lead, and to phase shift in the feedback loop when the output is heavily, or capacitively, loaded. To obtain low output impedance, the output stage is of the common collector type; and to avoid either unnecessary loading, or wasted battery voltage, choke-capacitance coupling is used. The collector dissipation is about double that given in the manufacturers' data; the 200 mW transistors were not available when the circuit was

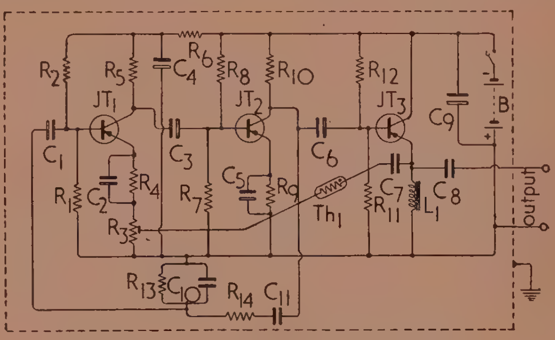


Fig. 2. Circuit of 1000 c/s oscillator

R_1 = 6.8 kΩ
R_2 = 27 kΩ
R_3 = 500 Ω
R_4 = 4·7 kΩ
R_5 = 6·8 kΩ
R_6 = 4·7 kΩ
R_7 = 10 kΩ
R_8 = 82 kΩ
R_9 = 680 Ω
R_{10} = 6·8 kΩ
R_{11} = 47 kΩ
R_{12} = 15 kΩ
R_{13} = 1·2 kΩ
R_{14} = 47 kΩ

C_1 = 1 μF, electrolytic
C_2 = 2 μF, electrolytic
C_3 = 2 μF, electrolytic
C_4 = 8 μF, electrolytic
C_5 = 6 μF, electrolytic
C_6 = 1 μF, electrolytic

C_7 = 0·1 μF, paper
C_8 = 0·25 μF, paper
C_9 = 50 μF, electrolytic
C_{10} = 0·02 μF, paper
C_{11} = 0·02 μF, paper

L_1 = 2H, 1500 Ω
Th_1 = thermistor type A5321

B = 9 V dry battery

JT_1, JT_2 = Mullard type OC70
JT_3 = Mullard type OC71

all resistors 1/10 W, 10% tolerance
all capacitors low-voltage types, 20% tolerance
Above values for components in feedback network give approximately 1000 c/s

developed. The summarized characteristics of the oscillator are:

Output: 1·0 V (r.m.s.) in loads from 700–10 000 Ω resistive and up to 0·1 μF capacitive for about 5% harmonic distortion.

Ratio of balance to unbalanced output: 70 dB (approx.).

Battery consumption: 5 mA at 9 V.

Capacitance to earth: 80 pF (in earthed metal box 6 × 6 × 3 in.).

PERFORMANCE OF THE UNITS IN BRIDGE CIRCUITS

Several test circuits were set up using screened decade resistance and capacitance boxes, and the results are recorded briefly here. The balance sensitivity is specified as the fractional change in setting which could be detected, in the arm or arms chosen for adjustment.

Bridge A: Two resistors of 1000 Ω and two of 10 000 Ω, one arm having a capacitance trimmer and one detector terminal being earthed. Balance sensitivity was better than 1 in 10^4 and residual output small.

Bridge B: Wien bridge with 0·1 μF capacitors and resistors in the range 1000–2000 Ω. Balance sensitivity 1 in 100; residual considerable owing to harmonics in the oscill output.

Bridge C: Maxwell inductance bridge with inductor of al 0·1 H and 15 Ω and capacitor of about 0·05 μF. Wa earth circuit used. Balance sensitivity 1 in 10^4 for capacita balance, 1 in 200 for resistance balance. The residual out due mainly to stray pick-up, was about 0·1 mA (f.s.d 0·5 mA).

Bridge D: Two capacitors of about 500 pF and two resis of about 1500 Ω, with Wagner earth. Balance sensiti 1 in 500, residual output about 0·1 mA.

CONCLUSION

It has been shown that the performance of the uni adequate for school or college use, with a considerable sa in cost, compared with commercial instruments. It w not be difficult to improve the performance by providi larger oscillator power and by tuning the detector ampli

REFERENCES

(1) KARO. *Electrical Measurements*, Pt. 2, Chap. 8 [Lon MacDonald and Co. (Publishers) Ltd., 1953.].
(2) VALLEY and WALLMAN. *Vacuum Tube Amplifiers*, p. (New York: McGraw-Hill Book Co. Inc., 1948).
(3) SHEA. *Principles of Transistor Circuits*, Chap. 5 (York: John Wiley and Sons, Inc., 1953).

A portable twenty-four channel kicksorter

By G. F. VON DARDEL, Tekn. Dr.,* AB Atomenergi, Department of Physics, Stockholm, Sweden

[*Paper first received* 19 *July, and in final form* 31 *August*, 1954]

A twenty-four channel kicksorter has been developed essentially on the principles of Wilkinson. The circuits contain twenty-five valves and eight relays. The whole instrument is easily portable and consists of two units, weighing 25 and 10 kg. Normal channel width is 2 V and the level of the bottom channel can be varied between 0 and 100 V. A simple stabilizing device is described which can be connected to the kicksorter for applications where a slow drift occurs.

With most detectors of nuclear radiation it is necessary to investigate the pulse spectrum by measuring, for example, the "bias curve" both before the counter is put into operation to determine the optimum discriminating level, and later to check on the consistency and reproducibility of the measurement.

With low counting rates or with complicated spectra, the point-by-point recording of a pulse spectrum is tedious. Mainly for this purpose we have developed a simple portable kicksorter, i.e. a multi-channel pulse size analyser, intended as a general service instrument for the rapid testing of detecting equipment.

Previous kicksorters(1–4) have, as a rule, been rather complicated and bulky instruments, reserved for more exacting measurements of complicated pulse size spectra, such as those encountered in the study of α-energies by means of a grid ionization chamber, or γ-energies with a scintillation spectrometer. For these applications the number of channels must be large enough to give adequate resolution and the stability must be good. With twenty-four channels and good stability the present instrument can also be used for many of these more exacting applications.

PRINCIPLES OF OPERATION

The principles of the present design are almost iden with those of the system described by Wilkinson,(3) altho in the detailed circuits, a number of simplifications and m fications have been made in order to reduce the numbe valves, and consequently the current consumption and w of the apparatus.

As indicated by the block diagram, Fig. 1, four parts be distinguished, namely an input unit, a coding unit, w converts the pulse size to a linearly-related number of pulses, a recording unit, which counts the number of pulses and records a count in a register, and a program unit, which controls the whole process. The waveform the points denoted by Roman numerals in Fig. 1 are g in Fig. 2.

The apparatus can accept negative pulses between 2 150 V in amplitude. Normal channel width is 2 V, so a 50 V section of the spectrum can be analysed in one meas ment. The position of the analysed section can be sh by means of a potentiometer which varies the d.c. lev the pulses between 100 and 200 V. An input circuit of gain and low output impedance applies the incoming p waveform I, to two diode discriminators, biased to a

---

* Now at CERN Laboratory Group, Geneva, Switzerland.

100 V. If the peak of the pulse extends below the dis-iminator bias, it produces at the output of discriminator 1 lengthened pulse, waveform II, which goes to the coding nit.

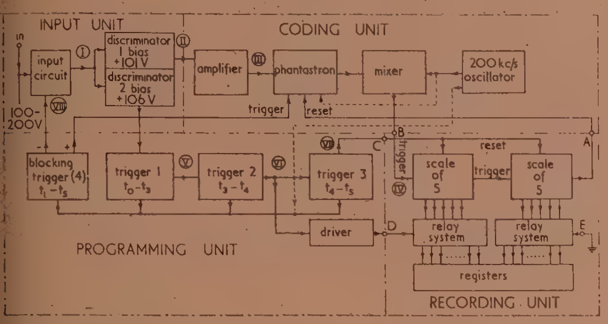


Fig. 1. Block diagram. The Roman numerals refer to the waveforms of Fig. 2. The connexions to the recording unit *A* to *E* refer to the detailed circuit diagrams of Figs. 3 and 4

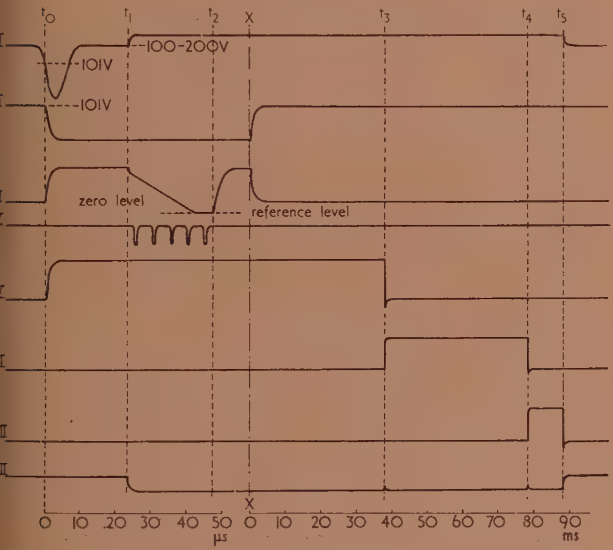


Fig. 2. Waveforms

Note change of time scale at X

The programming unit is triggered by a pulse from dis-iminator 2. It consists of a chain of three univibrators, iggers 1 to 3, which generate the waveforms V, VI and VII. nese signals are mixed and afterwards shaped by an eriodic trigger 4. The resulting waveform VIII blocks the put circuit with a certain delay $(t_1 - t_0)$ after the triggering the programming circuit, so that no further pulses are lmitted to the discriminators while the count is being corded.

In the coding unit the lengthened pulse from discriminator 1 inverted by a paraphase amplifier. The resulting waveform I is applied to a phantastron sweep circuit which is normally ocked. The sweep is started by a trigger pulse from the ogramming unit at time t_1 and terminates at the time t_2 nen the voltage of waveform III reaches a given reference vel. During the sweep, the length of which is a linear nction of the pulse size, a gating pulse is applied to a mixer valve, and modulates a 200 kc/s signal supplied by an oscillator. The gated signal, waveform IV, consists of a train of "code pulses."

In Wilkinson's(3) kicksorter the gating signal occurs at random with respect to the phase of the coding oscillator. This has the effect of making the "window curve" of the analyser triangular. It also means that the first or last pulse in the train of code pulses may occasionally be distorted if they coincide with the edges of the gating signal, so that shaping of the code pulses is necessary before they are presented to the recording unit. In the present design the beginning and end of the gating signal are synchronized with the oscillator, as indicated by the broken connexions in Fig. 1. With this synchronization the window curve becomes more nearly rectangular, and the code pulses obtained from the mixer always have a uniform shape.

In the recording unit the number of code pulses are counted by two scale-of-five circuits in series. When these circuits stop, they actuate a system of relays which connects the proper register in an array of twenty-five registers to a driving circuit controlled by trigger 2 in the programming unit. When trigger 2 triggers at time t_3 a count is recorded. Finally, the scaler is reset to zero at time t_4 by waveform VII from trigger 3 in the programming unit. The input circuit is opened at t_5 and the circuits are ready to record another pulse. Since $(t_5 - t_0)$ is about 90 ms the maximum counting rate is 11 pulses/s.

DETAILED CIRCUITS

Circuit diagrams for the input, coding and programming units are shown in Fig. 3, and for the recording unit in Fig. 4. The input circuit valves V_1 and V_2 form a White cathode follower.(5) The pulses to be sorted are applied to the right-hand grid of V_1, the bias being supplied by the ten-turn potentiometer RV_1. The left-hand half of V_1 is a blocking valve. The input is opened by opening the switch S_1. It can also be opened by applying a suitable negative gating pulse on the left-hand grid of V_1 from an external circuit, if the kicksorter is to be sensitive only to pulses occurring in coincidence with other events. The signal VIII from trigger 4 for the automatic blocking of the input circuit during recording is introduced through R_{32}, R_{33} and R_4 on the control grid of V_2.

The pulse passing through discriminator 1 (V_{3a}) is lengthened by the memory circuit C_8–R_{13}, which stores the pulse-size information for about 20 μs until the coding process starts at t_1. The time constant, 1 ms, is short enough so that no memory persists from the preceding pulse.

Discriminator 2 consists of the diode-connected triode V_{4a}. In order to avoid coupling between the two discriminators their diodes should be contained in different bulbs and the bias provided by independent potential dividers.

The paraphase amplifier V_{5a} has a gain of somewhat less than unity. The plate is connected to the phantastron V_6, which is normally non-conducting, and to the clamping diode V_{3b}. The phantastron is of the conventional screen-coupled type(6) and is triggered on the suppressor by a positive pulse from trigger 4. During the sweep the suppressor is clamped to ground potential by D_2 and the screen voltage to +100 V by D_1. The latter feature improves the linearity of the coding circuit considerably.

During the sweep the anode potential decreases at a rate determined by C_{11}, R_{26} and the setting of the potentiometer RV_3, until the anode is clamped by V_{3b}. The control grid potential of V_6 will then increase, increasing the screen grid current to a point where the phantastron reverts to the quiescent state. A small condenser C_{15} synchronizes the resetting process with the 200 kc/s oscillator.

The reference potential on the anode of the clamping diode V_{3b} is composed of the potential acquired by the condenser C_7 which corresponds to the zero level of waveform III and a voltage step across RV_2, the object of which is to make the coding circuit work in the linear part of its range even for very small pulses. When trigger 1 is triggered, about 10 mA flows through RV_2, and the anode potential of V_{3b} is decreased by a voltage adjustable between 0 and 10 V.

The suppressor of the phantastron is connected to the suppressor of the mixer valve V_7 and a 200 kc/s signal from the Hartley oscillator V_{8a} is fed through C_{14} on the control grid. The gated code pulses B for the recording unit a taken from the anode of V_7.

In the progamming unit, triggers 1 to 3 are essentia identical univibrators V_{10} to V_{12}. Trigger 1 takes somewh higher current since it has to react on fast triggering pul from discriminator 2. V_{13} is the driving circuit for registers and also operates a totalling register in the an circuit.

The mixing of the signals from the three triggers and c properly-phased synchronizing signal from the oscillato performed by the network R_{44}, R_{51}, R_{59} and C_{16}. resulting waveform is applied to the Schmitt(7) trigge through the simple diode pump D_5–C_{20}. The delay (t_1 –

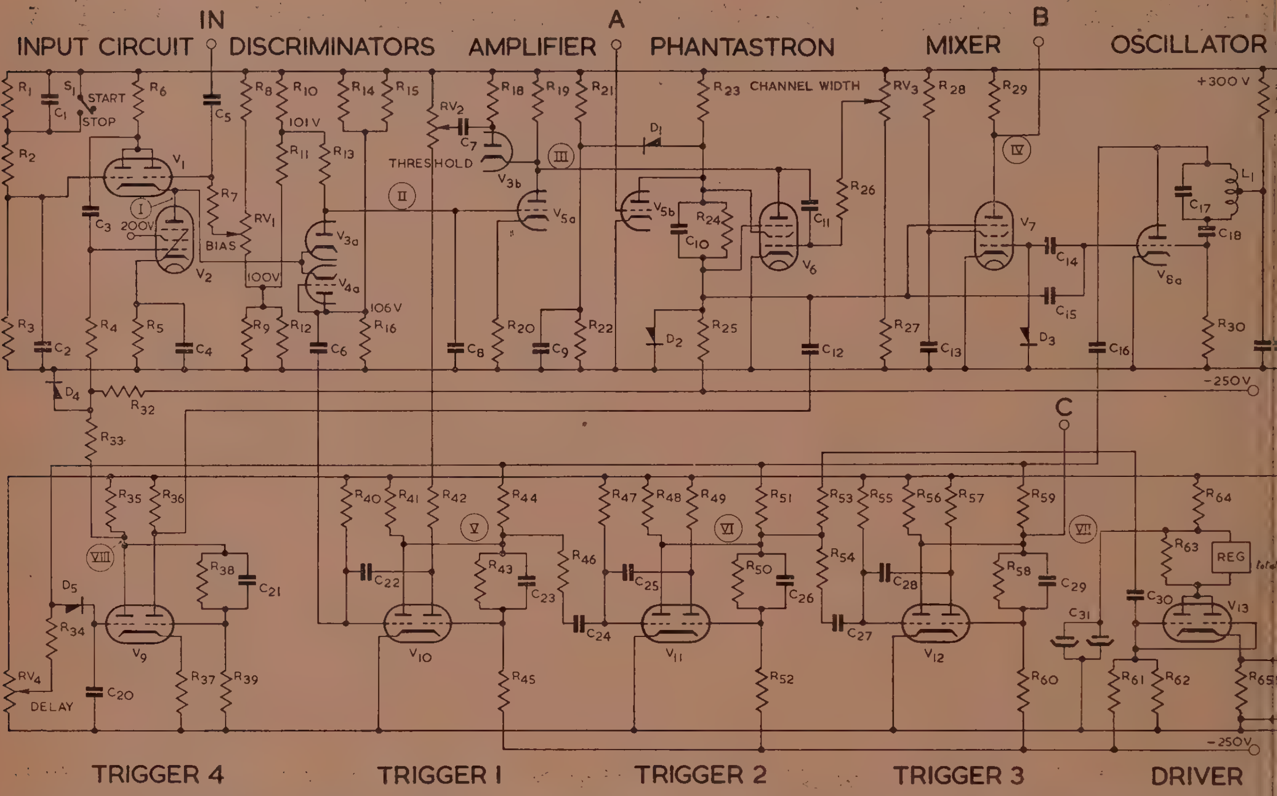


Fig. 3. Circuit diagram of input, coding and programming units. In the list of components the valves actually used in the experimental model are given but the more modern types within brackets will probably perform as well and save space and heater consumption. Roman numerals refer to the waveforms of Fig. 2

$R_1 = 8{\cdot}2$ MΩ
R_2, R_3 = 1 MΩ
R_4 = 100 kΩ
R_5 = 1 kΩ, w.w.
$R_6 = 4{\cdot}7$ kΩ
R_7 = 1 MΩ
R_8, R_9 = 100 kΩ, w.w.
R_{10} = 22 MΩ
R_{11} = 82 kΩ
R_{12} = 10 MΩ
R_{13} = 15 MΩ
R_{14} = 100 kΩ, w.w.
R_{15} = 1 MΩ
R_{16} = 50 kΩ, w.w.
R_{18} = 12 MΩ
R_{19}, R_{20} = 50 kΩ, w.w.
R_{21} = 220 kΩ
R_{22} = 100 kΩ
R_{23} = 68 kΩ
R_{24} = 100 kΩ
R_{25} = 400 kΩ
R_{26} = 15 MΩ
R_{27} = 50 kΩ, w.w.
R_{28} = 150 kΩ
R_{29} = 10 kΩ
R_{30} = 1 MΩ
R_{31} = 22 kΩ, 2 W
R_{32}, R_{33} = 200 kΩ

R_{34} = 1 MΩ
R_{35}, R_{36} = 10 kΩ, 2 W
R_{37} = 15 kΩ, 2 W
R_{38}, R_{39} = 100 kΩ
R_{40} = 5 MΩ
R_{41} = 39 kΩ, 2 W
R_{42} = 15 kΩ, 2 W
$R_{43} = 1{\cdot}5$ MΩ
R_{44} = 680 kΩ
$R_{45} = 2{\cdot}2$ MΩ
R_{46} = 470 kΩ
R_{47} = 5 MΩ
R_{48}, R_{49} = 100 kΩ
$R_{50} = 1{\cdot}5$ MΩ
R_{51} = 680 kΩ
$R_{52} = 2{\cdot}2$ MΩ
R_{53}, R_{54} = 470 kΩ
R_{55} = 5 MΩ
R_{56}, R_{57} = 100 kΩ
$R_{58} = 1{\cdot}5$ MΩ
R_{59} = 680 kΩ
$R_{60} = 2{\cdot}2$ MΩ
R_{61} = 22 MΩ
R_{62} = 1 MΩ
$R_{63} = 1{\cdot}5$ kΩ, 2 W
$R_{64} = 1{\cdot}2$ kΩ, 2 W
R_{65} = 33 kΩ

RV_1 = 10-turn Helipot, 100 kΩ
RV_2 = 1 kΩ, w.w.
RV_3 = 100 kΩ, w.w.
RV_4 = 1 MΩ

V_1 = 6J6
V_2 = 6AK5
V_3 = 6H6 (6AL5)
V_4 = 6J6 (6AL5) (V_{4b} unused)
V_5 = 6SN7 (12AU7)
V_6, V_7 = 6AS6
V_8 = 6SN7 (12AU7) (V_{8b} unused)
V_9 = 6J6 (12AU7)
V_{10} = 6J6 (12AT7)
V_{11}, V_{12} = 6J6 (12AX7)
V_{13} = 6J6 (12AU7)

D_1–D_5 ≑ RCA 1N34 or Philips OA50

C_1, $C_2 = 0{\cdot}001$ μF
C_3 = 47 pF
C_4, $C_5 = 0{\cdot}01$ μF
$C_6 = 0{\cdot}001$ μF
$C_7 = 0{\cdot}1$ μF
C_8 = 68 pF

$C_9 = 0{\cdot}1$ μF
C_{10} = 27 pF
C_{11} = 47 pF, mica
C_{12} = 47 pF
$C_{13} = 0{\cdot}05$ μF
C_{14} = 10 pF
$C_{15} = 4{\cdot}7$ pF
$C_{16} = 6{\cdot}8$ pF
C_{17} = 2200 pF
C_{18} = 22 pF
$C_{19} = 0{\cdot}1$ μF
C_{20} = 68 pF
C_{21} = 40 pF
$C_{22} = 0{\cdot}01$ μF
C_{23} = 22 pF
$C_{24} = 0{\cdot}001$ μF
$C_{25} = 0{\cdot}01$ μF
C_{26} = 22 pF
$C_{27} = 0{\cdot}001$ μF
$C_{28} = 0{\cdot}005$ μF
C_{29} = 22 pF
$C_{30} = 0{\cdot}1$ μF
$C_{31} = 2 \times 8$ μF, electrolytic, 450 V

$L_1 \sim 300$ μH tunable (with powder core)
L_1, C_{17} is tuned to 200 kc/s

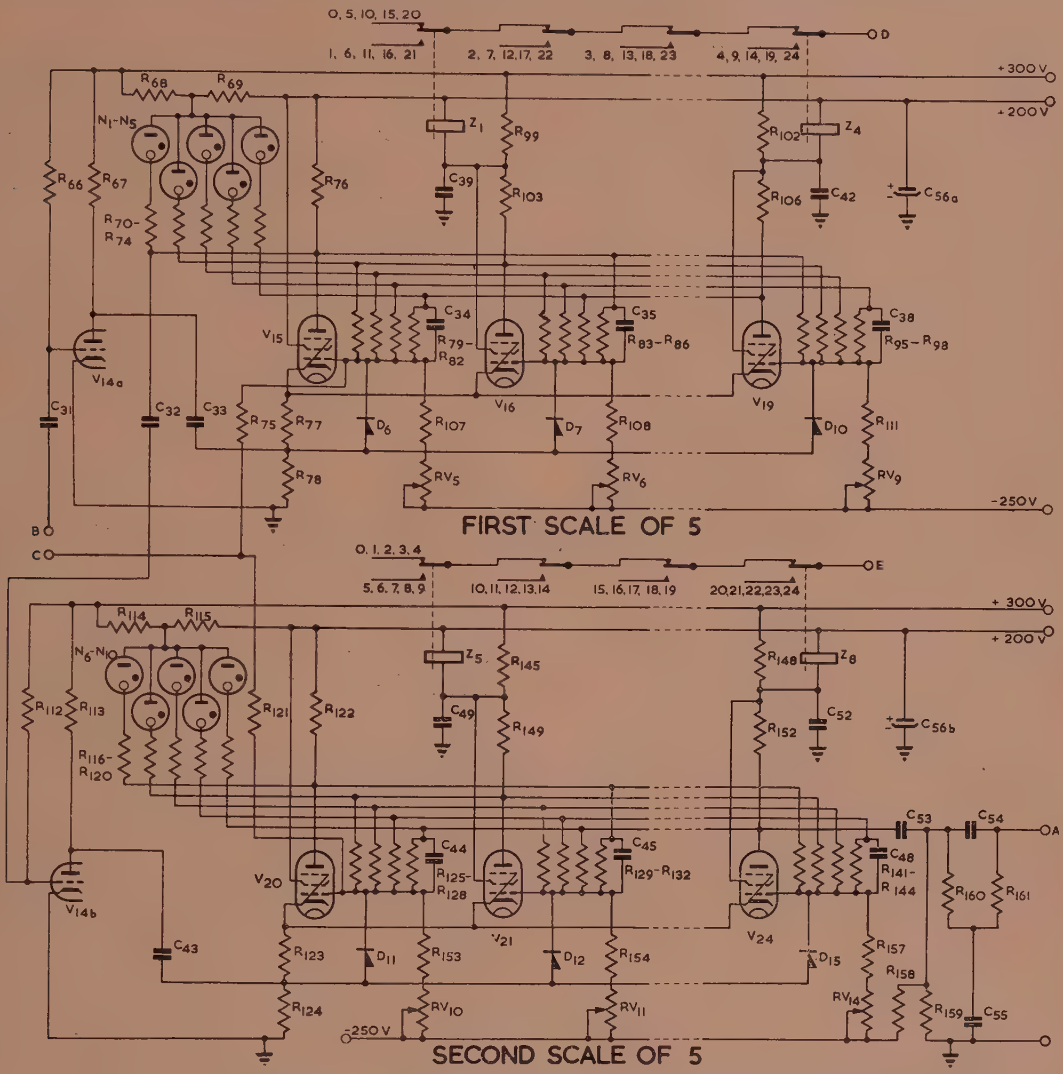

0, 5, 10, 15, 20
1, 6, 11, 16, 21
2, 7, 12, 17, 22
3, 8, 13, 18, 23
4, 9, 14, 19, 24
D
+300 V
+200 V
R68
R69
N1-N5
R66
R67
R70-R74
R76
Z1
R99
C39
R103
R102
Z4
R106
C42
C56a
C34
R79-R82
C35
R83-R86
C38
R95-R98
V15
V14a
V16
V19
C31
C32
C33
R75
R77
D6
R107
D7
R108
D10
R111
R78
RV5
RV6
RV9
-250 V
B
C
FIRST SCALE OF 5
0, 1, 2, 3, 4
5, 6, 7, 8, 9
10, 11, 12, 13, 14
15, 16, 17, 18, 19
20, 21, 22, 23, 24
E
+ 300 V
+ 200 V
R114
R115
N6-N10
Z5
R145
R148
Z8
R112
R113
R121
R122
C49
R149
C52
R152
C56b
R116-R120
C53
C54
A
C44
R125-R128
C45
R129-R132
C48
R141-R144
R160
R161
V20
V14b
V21
V24
C43
R123
D11
R153
D12
R154
D15
R157
R158
RV14
R159
C55
R124
RV10
RV11
-250 V
SECOND SCALE OF 5

Fig. 4. Circuit diagram of recording unit for the twenty-five channel experimental model

R_{66} = 470 kΩ
R_{67} = 56 kΩ
R_{68} = 5 kΩ, 2 W
R_{69} = 1·5 kΩ, 2 W
R_{70}–R_{74} = 470 k
R_{75} = 470 kΩ
R_{76} = 15 kΩ
R_{77} = 1 kΩ
R_{78} = 6·8 kΩ
R_{79}–R_{98} = 250 kΩ
R_{99}–R_{102} = 56 kΩ
R_{103}–R_{106} = 15 kΩ
R_{107}–R_{111} = 150 kΩ
R_{112} = 470 kΩ
R_{113} = 56 kΩ

R_{114} = 1·5 kΩ
R_{115} = 5 kΩ, 2 W
R_{116}–R_{120} = 470 kΩ
R_{121} = 470 kΩ
R_{122} = 15 kΩ
R_{123} = 1 kΩ
R_{124} = 5·6 kΩ
R_{125}–R_{144} = 250 kΩ
R_{145}–R_{148} = 58 kΩ
R_{149}–R_{152} = 15 kΩ
R_{153}–R_{157} = 150 kΩ
R_{158} = 1 MΩ
R_{159} = 5 MΩ
R_{160} = 220 kΩ
R_{161} = 220 kΩ

RV_5–RV_{14} = 50 kΩ, w.w.

N_1–N_{10} = Starting voltage: 90 V
Operating voltage: 70 V

C_{31} = 10 pF
C_{32} = 4·7 pF
C_{33} = 0·01 μF
C_{34}–C_{38} = 10 pF
C_{39}–C_{42} = 0·1 μF
C_{43} = 0·01 μF
C_{44}–C_{48} = 10 pF
C_{49}–C_{52} = 0·1 μF
C_{53} = 0·001 μF

C_{54} = 22 pF
C_{55} = 820 pF
C_{56} = 2 × 16 μF, electrolytic, 450V

V_{14} = 6J6 (12AU7)
V_{15}–V_{19} = 6AK5
V_{20}–V_{24} = 6AK5

D_6–D_{15} = RCA 1 N34 or Philips OA50

Z_1–Z_8 = 1000 Ω coils, two-way switching contacts

the triggering is determined by the rise-time of the mixed aveform and by its d.c. level, which can be adjusted RV_4.

The recording unit, Fig. 4, contains two ring circuits of the pe developed by Lawson.(8) The circuit has the advantage er the Sharpless ring circuit(9) used by Wilkinson(3) in that e power consumption is lower, since only one valve in each ng is conducting at a time, and that the coils of the relays $_1$ to Z_8 can be connected directly into the anode and screen rcuits without special driving circuits.

The circuit is reset to the initial state with V_{15} and V_{20} nducting by application of a positive current pulse of out 300 μA to the grids of these valves. This current pulse is taken through the resistors R_{75} and R_{121} from the output C of trigger 3.

The coils of the relays are decoupled by 0·1 μF condensers C_{39}–C_{42}, C_{49}–C_{52}, and form damped ringing-circuits. When a relay closes, a slow negative pulse is obtained across the coil. Since the other valves of the ring circuit are already nonconducting, this negative pulse has no bad effects. Care has, however, to be taken that the ringing-circuits are sufficiently damped so that no positive overswing follows the negative pulse, since positive pulses may cause spurious switching of the circuit. It is also essential that the normally conducting valves, V_{15} and V_{20}, have no relay coils in their anode circuits, since otherwise a slow positive pulse would be produced when the current through these coils is interrupted. Furthermore, the reset pulse applied to the grid of V_{15} and V_{20} must be sufficiently long to allow the positive transient across the conducting relay coil to disappear.

Each relay in the ring circuits operates a two-way switching contact. If the coding circuit, for example, produces twenty code pulses the first ring will make four full cycles and stop in a state with V_{15} conducting again. The second ring receives four pulses from the first ring and stops in a state with V_{24} conducting. In the second ring relay Z_8 closes and connects to the earthed terminal E of the driving circuit, the common terminal of registers 20, 21, 22, 23 and 24. In the first ring all relays are open and the live terminal D of the driving circuit is connected through the switching contacts of relays Z_1 to Z_4 to the common terminal of registers 0, 5, 10, 15 and 20. When, somewhat later, the driving circuit operates, only register 20 will receive the full driving voltage and record a count. Of the remaining registers, eight will receive $\frac{4}{9}$ and sixteen only $\frac{1}{9}$ of full voltage and will not be energized sufficiently to count. They will, however, increase the load on the driving circuit by a factor of 2·6. Wilkinson used an array of rectifiers to block the undesired current paths.

A threshold pulse which just triggers the programming unit is adjusted to give rise to six code pulses by means of RV_2, and will record on register 6, which thus corresponds to the first channel. A large input pulse which produces thirty-one code pulses would, after one full cycle, also be recorded on register 6. To avoid this recycling of the recording unit the phantastron sweep is terminated forcibly after the thirtieth code pulse. Register 5 then records all the largest pulses which give more than twenty-nine code pulses. The signal A for terminating the sweep is taken from the anode of V_{24} through a resistor-condenser network and applied to the grid of the normally nonconducting valve V_{5b}.

Although the present recording system performs quite well, it is believed that a system based on binary scalers instead of the ring-of-five circuits would be easier to adjust and more economical in valves and relays for a given number of channels. A proposed recording system using binary units will have sixty-three channels and is controlled by two scale-of-eight circuits in series. In each scale-of-eight the three binary units operate relays, having one, two and four two-way switching contacts respectively. The scaling circuits may be of the type described by Higinbotham, Callagher and Sands(10) and resetting may be achieved by a positive current pulse on the proper grid as with the circuit of Fig. 4. With a binary system it is probably best to use buffer stages between the binary unit and the relay, as done by Wilkinson.(3)

A few modifications to the rest of the circuit would be necessary. The speed of the phantastron sweep should be adjusted to give a normal channel width of 0·8 V, so that sixty-three channels can be accommodated within the 50 V capacity of the pulse analyser. The potentiometer RV_2 should be adjusted to give seventeen code pulses for a threshold pulse. If the circuit is connected so that the scaler, after each count, is reset to position 48 rather than to 0 a threshold pulse will be recorded in register 1. In order to avoid recycling the phantastron must be forcibly reset when the scaler goes the second time from position 63 to 0. Trigger 3 will have to carry more current, since it now has to provide resetting current for six scaling circuits instead of two. The driving valve V_{13} would have to be reinforced, since there are now more idle registers in parallel with the one that operates.

The power supply is of the model 50 type,(11) developed at
Los Alamos, with the addition of a −250 V supply. T
power consumption is 90–110 mA (depending on the count
rate) at +300 V, and 20 mA at −250 V. Heater consumpt
is 7·5 A at 6·3 V. With the present power supply, which
somewhat over-dimensioned, the weight of the main unit
25 kg. The registers are housed in a separate cabinet weigh
10 kg.

TESTING AND PERFORMANCE

For testing, a built-in precision pulse generator has be
found useful. A thyratron is triggered by pulses from
neon lamp relaxation oscillator running at about 8 pulse
Variations in the operating voltage are small compared
the 300 V amplitude of the pulses at the anode of the thyratr
Calibration pulses of between 2 and 100 V in amplitude c
be selected with an attenuator and presented to the kicksor
instead of the external pulses.

With a constant pulse height the proper functioning of t
kicksorter can be checked by varying the bias potentiome
RV_1. The linearity was found to be better than 0·1 V o
the entire range. This implies that the channel widths a
the same for all channels to within 5%, and for most chann
to considerably better than this value. Variations in t
mains voltage by ±10% produce less than 0·1 V shift
the spectrum. Except for a short warming-up period, dri
are less than 0·1 V over periods of hours or days. Larg
drifts probably occur over longer periods when the chara
teristics of the valves change.

CONCLUSIONS

The present design is intended for the analysis of puls
having rise-times in the region 1 to 20 μs. For longer ri
times the delay $t_1 - t_0$ before the input circuit is block
must be increased to allow the pulse to attain full heig
For shorter rise-times it is necessary either to pretreat t
pulses to give them sufficient duration, or to modify t
input circuit so that it can discharge the memory conden
C_8 at a faster rate.

In spite of the 90 ms dead-time of the kicksorter the sha
of the pulse spectrum will be recorded correctly even at hi
counting rates when severe counting losses occur. At ve
high counting rates, however, where there is an apprecia
probability that several pulses will arrive within 20 μs bef
the input circuit is blocked, the lower part of the spectru
will be decreased with respect to the upper, since only t
highest of the pulses will be recorded.

The present analyser should be well suited for applicatio
where good linearity and stability is of importance a
where the limited counting rate is sufficient. The simp
construction and low cost, as well as the portability of th
kicksorter, should make it applicable to many problem
which have not warranted the use of a conventional, mo
expensive, pulse-size analyser. The low weight should, f
example, make it useful for cosmic-ray research, perha
even under airborne conditions. Equipping the relays wi
more contacts would increase the versatility of the instr
ment, since various experimental conditions can aut
matically be taken into account in the analysis of the puls
such as the type of coincidences occurring in associat
counting equipment.

The low speed of the kicksorter is rarely a major d
advantage when continuous sources of radiations a
measured. When working at maximum speed abo
40 000 pulses will be recorded in one hour, and it is probab
that only on rare occasions will this number of pulses
insufficient or the time excessive. The kicksorter is, howeve

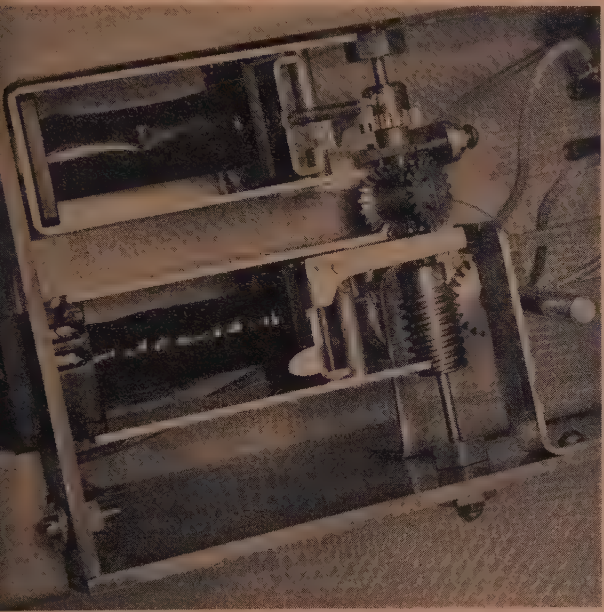
suitable for work with some of the new pulsed accelerators, h as the Cosmotron which emits radiation in short bursts ather long intervals. The kicksorter will then only be able ecord one event per burst, and the counting rate cannot eed the burst frequency.

ACKNOWLEDGEMENTS

he author is grateful to Mr. C. Taylor and Mr. S. Lindhe many inspiring discussions.

APPENDIX

lutomatic stabilizer. For applications where very high olution is necessary and where, at the same time, the nting rate is so low that very long measurements are ded, the stability of the equipment becomes of primary ortance. Wilkinson(12) has described a device for ilizing a proportional chamber by a feedback acting on high voltage supplied to the chamber. We have con- ucted an instrument which is similar in principle but of re general use since it allows the feedback to be applied an arbitrary point in the circuit. As shown in Fig. 5, the ice consists of the mechanisms of two message registers, m which the digital wheels have been removed and laced by a differential gear and a worm which drives a r on the shaft of a potentiometer. The registers operate potentiometer stepwise in opposite directions.



ig. 5. Stabilizing device for locking the pulse analyser on a peak of the pulse spectrum

When the stabilizer is used in conjunction with the kick- ter, two registers in the kicksorter, one on the lower and on the upper slope of a prominent peak in the pulse ctrum, are replaced by a special type equipped with relay tacts, which close each time a count is recorded and rgize the coils of the stabilizer.

The potentiometer in the stabilizing device is most easily nected so as to adjust the bias of the kicksorter, but it also control the gain of the preceding amplifier or the h voltage on the detector. If the proper polarity is chosen stabilizer will keep the peak in the pulse spectrum centred, so that the counting rates in the two channels are equal, and any slow drift of the operating conditions will be counteracted by the device. Due to the statistical character of the pulses the stabilizer will also cause a broadening of the peak. This broadening has to be kept small. If the equilibrium counting rate in each of the two channels is n, the slope per channel of the pulse spectrum is $+n_1$ and $-n_2$ at the lower and upper slope of the peak respectively, and each feedback pulse produces a shift of the peak by Δ channels, the r.m.s. value of the statistical broadening is

$$\sigma = (\Delta n/(n_1 + n_2))^{\frac{1}{2}} \text{ channels} \qquad (1)$$

as can be shown by a straightforward mathematical treatment similar to the one given by Wilkinson.(12)

If, without stabilization, the peak position would show a constant drift of δ channels/s, the stabilizer will counteract the drift by shifting the peak by an amount

$$x = \delta/[2(n_1 + n_2)\Delta] \qquad (2)$$

The stabilizer has been used in our laboratory in connexion with measurements of the α-spectrum of the uranium isotopes by means of a grid ionization chamber and the twenty-five channel kicksorter. The channel width corresponded to 1% of the ^{234}U pulse height. Two channels straddling the ^{238}U peak of the pulse spectrum were used to control the current in the two coils of the stabilizer. The counting rate n and the slope of the spectrum n_1 and n_2 in these channels were at equilibrium:

n = 60 pulses/h and channel
n_1 = 70 pulses/h and (channel)^2
n_2 = 100 pulses/h and (channel)^2

The feedback Δ per pulse has to be chosen so small that the statistical broadening of the spectrum as given by equation (1) does not appreciably decrease the resolution of the measurement. If we choose a feedback Δ of 0·03 channel widths the r.m.s. value of the statistical broadening becomes 0·1 channel widths, insignificant compared to the inherent resolution of the kicksorter itself. With this feedback the stabilizer will keep the spectrum stable within 0·1 channel widths according to equation (2) if the drift is less than 1 channel/h.

REFERENCES

(1) Freundlich, H. F., Hincks, E. P., and Ozeroff, W. J. *Rev. Sci. Instrum.*, **18**, p. 90 (1947).
(2) Baldinger, E., and Casale, R. *Helv. Phys. Acta*, **20**, p. 230 (1947).
(3) Wilkinson, D. H. *Proc. Cambridge Phil. Soc.*, **46**, p. 508 (1950).
(4) Hutchinson, G. W., and Scarrott, G. G. *Phil. Mag.*, **42**, p. 792 (1951).
(5) Moody, N. F., Battel, W. J., Howell, W. D., and Taplin, R. H. *Rev. Sci. Instrum.*, **22**, p. 551 (1951).
(6) Chance, B., Hughes, V., MacNichol, E. F., Sayre, D., and Williams, F. C. *Waveforms*, Radiation Laboratory Series, **19** (New York: McGraw-Hill Book Co. Inc., 1949).
(7) Schmitt, O. H. *J. Sci. Instrum.*, **15**, p. 24 (1938).
(8) von Dardel, G. *Appl. Sci. Res.*, *B3*, p. 206 (1953).
(9) Sharpless, T. K. *Electronics*, **21**, p. 122 (1948).
(10) Higinbotham, W. A., Gallagher, J., and Sands, M. *Rev. Sci. Instrum.*, **18**, p. 706 (1947).
(11) Elmore, W., and Sands, M. *Electronics*, National Nuclear Energy Series, Vol. 1 (New York: McGraw-Hill Book Co. Inc., 1949).
(12) Wilkinson, D. H. *J. Sci. Instrum.*, **27**, p. 36 (1950).

A slide rule technique for calculating neutron energies from tracks in nuclear emulsions

By J. P. Scanlon, B.Sc.,* Physics Department, University of Liverpool

[*Paper first received* 7 *July*, 1954, *and in final form* 13 *April*, 1955]

The calculation of neutron energies from the ranges of proton recoils is reduced to a form suitable for use with a slide rule. The modifications required for a standard slide rule and the method of operation are described. The technique can be used for all neutron energies greater than 1 MeV.

When measuring fast neutron spectra by the nuclear emulsion technique described, for example, by Rotblat,(1) one of the more laborious stages in the process is the calculation of the incident neutron energy from the microscope measurements made on each proton recoil track in the emulsion. The simplified measuring and calculating system, described by Gibson,(2) is readily applicable only when the neutron spectrum being measured covers a limited range of energies.

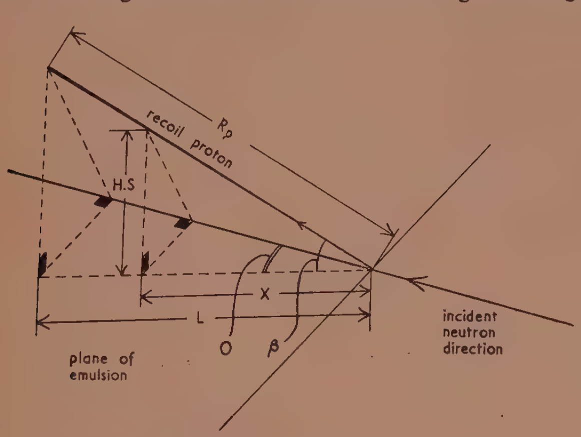


Fig. 1. Recoil proton measurements

The usual measurements made on a proton recoil yield the following information. (See Fig. 1.)

(*a*) The projected range L of the track in the plane of the emulsion (which contains the incident neutron direction).

(*b*) The angle θ between the projected range and the incident neutron direction.

(*c*) The amount H by which the track dips in the processed emulsion over a standard distance X of its projected range from the point of origin of the recoil. The true dip of the track over this distance in the unprocessed emulsion will then be $H.S$ where S is the shrinkage factor of the emulsion during development. The true dip angle β will be given by the relation

$$\sec\beta = [1 + (H.S/X)^2]^{\frac{1}{2}} \qquad (1)$$

The upper limits to the values of θ and β which are accepted are usually set at somewhere between 10 and 15°.

The calculation of the neutron energy then proceeds as follows:

$$\text{proton range } R_p = L\,.\sec\beta \qquad (2)$$

$$\text{proton energy } E_p = f(R_p) \quad \text{(range } \textit{versus} \text{ energy relation)} \qquad (3)$$

$$\text{neutron energy } E_n = E_p\,.\sec^2\beta\,\sec^2\theta \qquad (4)$$

The present object is to reduce this calculation to a form which it can be carried out on a slide rule in the smalle number of steps. Combining equations (2) and (3) we obta

$$E_p = f(L.\sec\beta) \qquad ($$

which it is convenient to rewrite as

$$E_p = f(L).[f(L.\sec\beta)/f(L)] \qquad (5$$

The expression in square brackets varies only slowly wi L and β, because $\sec\beta$ varies only slightly from unity ov the range of interest of β, and may be regarded as a correctin term to $f(L)$. In fact the range *versus* energy relation ma be written in the approximate form

$$E_p \simeq K.R_p^n \qquad ($$

where K and n are constants over the region to be considere If this approximation is inserted into the "correcting term" equation (5*a*) the equation immediately becomes

$$E_p = f(L).\sec^n\beta \qquad ($$

Finally, substituting in equation (7) for E_p from equation (and for β from equation (1) we obtain

$$E_n = f(L).[1 + (H.S/X)^2]^{(1+n/2)}.\sec^2\theta \qquad ($$

or

$$\log E_n \doteq \log f(L) + \log[1 + (H.S/X)^2]^{(1+n/2)} + \log\sec^2 \qquad ($$

The calculation can now be made on a slide rule with fou suitably figured logarithmic scales in

$$E_n,\ f(L),\ [1 + (H.S/X)^2]^{(1+n/2)} \text{ and } \sec^2\theta$$

These scales will be known as the E_n, L, H and θ scal respectively.

The H scale is the only one involving the approximation equation (6), which need not be very accurate because th correction to E_n introduced by the term is only 9% fo $\beta = 15°$. From the data for Ilford C2 emulsions given b Gibson, Prowse and Rotblat(3) the author suggests that fo the energy range 1 to 10 MeV a value for n of 0·609 is suitabl and between 10 and 20 MeV $n = 0{\cdot}586$ should be used.

The rule may be constructed from an ordinary slide ru as follows. The D scale (usual slide rule nomenclature) used without modification as the E_n scale from 1 to 10 Me or from 10 MeV upwards if required. The A scale is covere by a new L scale, calibrated against the E_n scale according the known range *versus* energy relation, and preferably in th units of measurement of the microscope being used. The and θ scales are drawn on the slide of the rule, and marke in convenient units of H and θ. If desired, several H scal may be drawn to allow for variations in S or in the chose values of X.

A portion of a typical rule is shown in Figs. 2(*a*) and (In this case the scales have been calculated for a microsco calibration of 1·18 scale divisions per micron, H in microns, $X = 100\ \mu$, and $S = 2\cdot3$. This value of $100\ \mu$ is normally a convenient one for X, but in cases where the track is shorter than this, or obviously bends within this distance, the dip must be measured over some shorter length from the point of origin. In such cases, separate H scales may be used, or alternatively the measured H may be multiplied by the appropriate factor to enable the $X = 100\ \mu$ scale to be used.

---

* Now at Atomic Energy Research Establishment, Harwell, Berks.

Operation of the rule is simply as follows [see Figs. 2(*a*) and (*b*)].

(1) Bring the zero of the H scale to the measured L. [Fig. 2(*a*).]

(2) Move the cursor to the measured H. [Fig. 2(*a*).]

(3) Bring the zero of the θ scale to the cursor. [Fig. 2(*b*).]

(4) Move the cursor to the measured θ. [Fig. 2(*b*).]

(5) Read off E_n on E_n scale opposite the cursor. [Fig. 2(*b*).]

The scales may quite well be drawn on stiff paper and fastened to the slide rule with cellulose tape. The author has found that with practice tracks can be dealt with at a rate of six per minute.

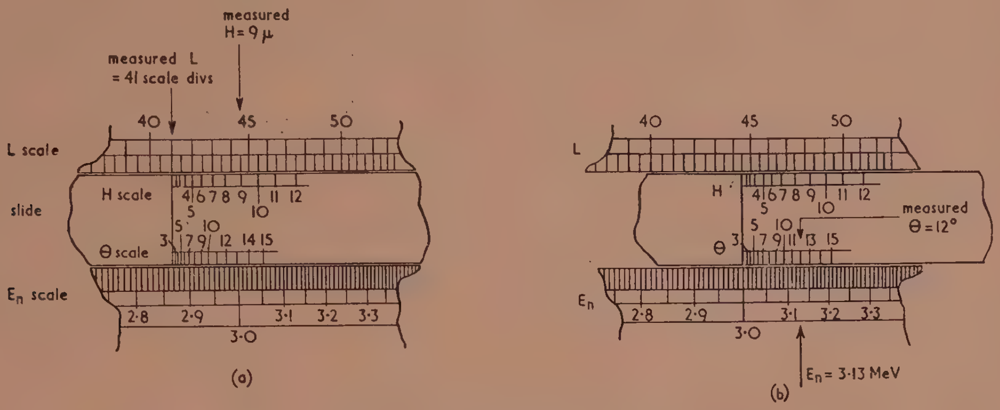


Fig. 2. Method of operation of a typical slide rule

REFERENCES

(1) Rotblat, J. *Progr. Nuclear Phys.*, **1** (1953).

(2) Gibson, W. M. *Phil. Mag.*, **44**, p. 297 (1953).

(3) Gibson, W. M., Prowse, D. J., and Rotblat, J. *Nature* [*London*], **173**, p. 1180 (1954).

A simple microcalorimeter for heat of solution measurements

By W. P. Hutchinson and A. G. White, B.Sc., Ph.D., Atomic Energy Research Establishment, Harwell, Berks.

[*Paper first received* 25 *November*, 1954, *and in final form* 12 *January*, 1955]

In an endeavour to simplify the temperature measuring equipment usually used in microcalorimetric work the performance, in a calorimeter, of five different types of thermistor has been examined. The selection of a suitable type for a given purpose and of the correct operating conditions is discussed. Details of the construction of a microcalorimeter, which uses a Dewar vessel of 50 ml. capacity and a thermistor as the temperature sensitive element, are given. Heat changes of approximately 1 cal can be measured with a precision of $\pm 0\cdot3\%$.

In a microcalorimetric process the quantity of heat liberated is usually of the order of a few calories. The fairly precise measurement of such small quantities of heat has previously called for equipment of considerable complexity and cost. In general, much depends upon whether the heat liberation can be made to occur in a small volume of liquid or whether, as in heats of dilution, large volumes are necessary. It is the former case with which this paper deals and it is shown that it is now possible to make such measurements with relatively simple and inexpensive apparatus.

Most microcalorimeters so far constructed appear to use thermocouples, with d.c. amplifier and galvanometers or precision potentiometers for temperature measurement, though wire-wound resistance thermometers have been used in some cases, e.g. by Westrum.(1) Very few attempts seem to have been made to exploit the very high temperature coefficient of resistance of thermistors to permit the construction of a simple apparatus using much less costly instruments for measurement purposes, although thermistors have been used for some years for ordinary calorimetric purposes by Skinner.(2)

Previous attempts to construct thermistor micro- or semi-micro-calorimeters appear to be confined to the work of Greenhill and Whitehead,(3) Hutchinson,(4) Zettlemeyer and others(5) and Hargreaves,(6) none of which provide a precision of more than a few per cent at the one calorie level, though a rather more elaborate twin system described by Bartell and Suggit(7) has a sensitivity of $\pm 0\cdot01$ cal. It was therefore decided to investigate the possibility of producing a simple and relatively inexpensive thermistor microcalorimeter and the results are described below.

DESCRIPTION OF THE CALORIMETER

The extent of the temperature rise observed in a given calorimetric process depends upon the thermal capacity of the system and the leakage modulus of the calorimeter. To obtain the maximum temperature rise, thus simplifying precise measurement, these two factors must be made as small as is possible. A limit is set to the extent to which thermal capacity can be reduced, largely by the size of the vessel necessary to contain the various components of the calorimeter and the volume of solvent with which it is necessary to work. For the authors' purposes a vessel with a total volume of 50 ml. was considered to be the smallest that could conveniently be used and the instrument is therefore based on a calorimeter vessel of this volume.

There seems to be little doubt that the most satisfactory method of achieving a low leakage modulus lies in the use of a Dewar vessel. In this case, the heat leakage depends on radiation across the vacuum jacket, conduction and convection by residual gas within the jacket and conduction along the walls of the vessel. Consequently, a highly evacuated, thin-walled flask would be expected to provide the most satisfactory results. The leakage modulus of normal commercial cylindrical Dewar vessels of 50 ml. capacity has therefore been compared with that of specially made flasks which were thin-walled and carefully evacuated, but otherwise identical with the commercial product. The values obtained were:

commercial Dewar vessel	$K = 0{\cdot}0078°$ C per °C per min
special vessel	$K = 0{\cdot}0012°$ C per °C per min

The charge in both cases was 40 ml. of water and the total volume 50 ml. The special vessel was constructed with glass of wall thickness 0·5 mm and was carefully evacuated. The dimensions were, as far as possible, those of the commercial Dewar vessel (28 mm diameter, 10 cm deep).

It is at once evident that a marked improvement in performance can be obtained by the use of the specially made vessel and this was therefore selected as the standard type to be used.

The calorimeter was designed to be completely immersed in a water bath and is fitted with a carefully machined polythene plug which carries the heater, stirrer, thermistor and sample holder and breaking device. A water-tight seal is obtained by compression on to a vacuum ring seal on top of the Dewar vessel, the top face of which is ground flat for this purpose. The complete assembly is shown in Fig. 1.

Stirring is by means of a flat glass paddle fused to the end of a short length of glass tubing which is then waxed to the end of the stainless steel stirrer shaft just below the polythene cap. The stirrer is driven by a small synchronous motor geared to give a final speed of 350 rev/min. Both the thermistor and the heater are enclosed in thin-walled glass pockets which make tight fits in the polythene plug. The heater, of 40 Ω, is wound non-inductively with manganin wire on a hollow cylindrical silver former insulated with Bakelite lacquer and embedded in naphthalene. Both current and potential leads are provided to enable the resistance to be checked under working conditions.

The thin-walled glass ampoules used to contain the samples are of uniform size and are made from thin wall (of the order of 0·2 mm) tubing by blowing into a mould.* These are crushed by releasing a spring-loaded plunger which also serves to hold the bulb in position. The entire calorimeter assembly is immersed in a large constant temperature water bath, being firmly fixed to the underside of a brass plate which acts as a lid to the bath. The bath temperature is controlled to $\pm 10^{-3}$° C and the necessary equipment has been previously described.(8) In view of the low leakage modulus achieved in this case a simpler system giving much less precise control of the bath temperature could undoubtedly be employed.

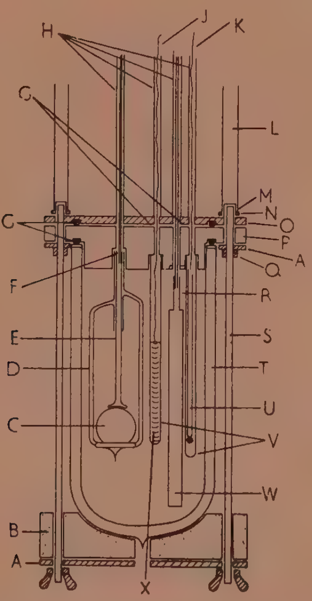


Fig. 1. Calorimeter assembly

A, brass ring; *B*, cork; *C*, standard glass sample bulb; *D*, glass; *E*, glass bulb breaker; *F*, waxed to stainless steel shaft; *G*, vacuum O-ring seals; *H*, brass tube brazed to top brass plate; *J*, leads to heater; *K*, leads to thermistor; *L*, brass support rod, tapped to take threaded rod at *M*; *N*, nut brazed to brass plate *O*; *P*, polythene cap; *Q*, lock nuts; *R*, stirrer shaft; *S*, threaded brass rod; *T*, silvered inner wall of Dewar vessel; *U*, thermistor; *V*, glass tubes; *W*, glass paddle, 0·6 × 7 cm; *X*, heater coil.

SELECTION OF THERMISTOR

General considerations. The selection of a suitable type of thermistor for use as a thermometer is governed by a number of factors, which include the physical size of the element, the temperature coefficient and the power sensitivity. The power sensitivity may be defined as the change in resistance produced by a given change in the power dissipated in the thermistor, or alternatively, as the increase in temperature of the element over that of the surroundings, produced by a given increase in power dissipation. In general, for thermometric purposes, as will be seen later, it is desirable to have the lowest possible value of power sensitivity.

The present requirement of small size and low thermal capacity restricts the choice to the bead-type of thermistor of which two varieties, manufactured by Standard Telephones and Cables Ltd., are readily available in this country. These are the type *F* in which the bead is encased in thin glass, and the type *A* in which the bead is in a gas-filled jacket. The manufacturers give the relative power sensitivities as type *F* 1·6° C/mW and type *A* 3·5° C/mW, while the temperature sensitivities in those examined by the authors appear to be perhaps rather greater for type *A* than for type *F* for a given nominal cold resistance. The other factor open to choice is the nominal resistance value of the element; both types are available in either low or high resistance forms. A high resistance type would appear the logical choice as this would give a larger value of resistance change for a given change in temperature than a low resistance type, and hence would avoid the difficulties usually associated with measurement of resistance to a small fraction of an ohm. In fact, however, other difficulties have been found to outweigh this advantage.

---

* Glass ampoules 1 cm in diameter with a wall thickness of approximately 0·05 mm were blown with the aid of a two-sectional mould, details of which are described in an Atomic Energy Research Establishment report CR 1376. It is understood that moulded ampoules of this type suitable for microcalorimetric work can be obtained in quantity from a lamp works. A platinum strip micro-furnace was also used for sealing these ampoules so that weighing operations could be carried out in an inert atmosphere inside a dry box, which was freed from moisture with desiccants since reactive compounds were being investigated.

Direct experimental test appears to be the only satisfactory method of determining which type of thermistor is the most suitable for a given application, and the performance of the following thermistors was therefore examined experimentally in the calorimeter.

Table 1. *Types of thermistor used*

Type	*F*		*A*		
Number	2311/300	1512/300	2321/100	1415/100	5513/100
Resistance at 20° C	2000	100 000	2000	10 000	500 000

Method of testing. The thermistor is employed in a bridge circuit, three arms of which are fixed, the fourth containing the thermistor and a suitable resistance box to permit balancing of the bridge. The power supply to the bridge must be highly stable as, should variations in voltage occur during operation, there will be corresponding variations in the thermistor resistance due to its power sensitivity. Initially, large capacity accumulators were used on the linear portion of the discharge curve, but eventually Le Carbone high capacity primary cells were found to be more satisfactory, provided that they were left on continuous discharge. If the discharge was interrupted the voltage rose and on further discharge took several hours to reach its steady value again. The bridge voltage was checked frequently with a potentiometer; Fig. 2 shows the circuitry used.

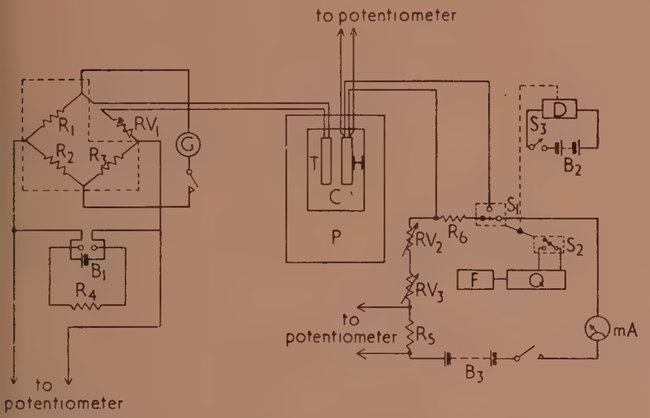


Fig. 2. Schematic diagram of apparatus. Components enclosed by broken line are mounted in *P* in an oil-filled tube

$R_1 = 10\ k\Omega$, $R_2, R_3 = 20\ k\Omega$ } Muirhead wire wound type A-70 $(\pm 0{\cdot}1\%)$
$R_4 = 13{\cdot}6\ k\Omega$ w.w.
$R_5 = 10\ \Omega$ Reichanstalt standard resistor
R_6 = "dummy" of same resistance as *H*

RV_1 = decade resistance box
RV_2 = coarse current control
RV_3 = fine current control

$B_1 = 1{\cdot}4$ V cell
$B_2 = 12$ V accumulator
$B_3 \simeq 12$ V $(1{\cdot}4$ V primary cells)

G = Cambridge short period galvanometer. Resistance, 600 Ω critical damping resistance, 2500 Ω sensitivity, 4500 mm/μA at 1 m
mA = milliammeter

S_1, S_2 = pairs of relay contacts
S_3 = "add heat" switch

T = thermistor
H = heater
C = calorimeter
P = constant temperature bath
F = standard frequency
Q = scaler
D – double-pole changeover high-speed relay

The experimental procedure was as follows. The calorimeter was fitted with the thermistor under test and then filled with a charge of 35 g of water. It was then immersed in the bath and brought to temperature equilibrium with its surroundings by means of the calorimeter heater, a process requiring some 4–5 h. A series of runs was then carried out in which heating curves were recorded for various heat inputs of up to 3 cal, permitting the linearity of response to be checked by comparison of the change in thermistor resistance with the known heat inputs. The quantities of heat were measured by accurately timing the passage of a known current through the calorimeter heater, the current being determined by measurement of the potential drop across a standard resistor in the circuit. The current was derived from a bank of Le Carbone primary cells which were normally left on discharge at the appropriate rate (50–100 mA) through a dummy resistor of the same value as the calorimeter heater. The current was switched to the calorimeter heater by the action of a double pole relay, the other pole of which served to switch on a standard type of scaler which counted the mains frequency. The time of passage of the current was thus given directly by the number of counts registered on the scaler. It is intended eventually to provide a very stable valve-maintained tuning fork with a frequency of 500 c/s which will serve as the primary time standard and be counted by the scaler instead of mains frequency. Frequent checks of mains frequency were made.

In recording a heating curve no attempt was made to balance the bridge for each reading; instead, the galvanometer deflexion was noted at convenient time intervals. Using this procedure, preliminary calibration to avoid galvanometer tangent error is essential. The change in resistance on heating was determined in the usual manner by extrapolation of the fore and after drift and measurement of the interval at the mid-point of the temperature rise.

Results of tests. The change of resistance with temperature of a thermistor is given by the relation

$$R = A \exp{(B/t)}$$

where R = resistance, A and B are constants, and T = absolute temperature. Hence, we have

$$\log R = \log A + (B/T)$$

and

$$\Delta \log R = B\Delta T/T_1T_2$$

represents the change in R to be expected for a change in temperature from T_1 to T_2. Where, as in the present case, ΔT is very small compared with T_1T_2, this reduces to

$$\Delta \log R = C\Delta T$$

where C is taken as a constant.

From this it is evident that a linear relation is only to be expected if the heat inputs to the calorimeter (which are proportional to ΔT) are plotted against $\Delta \log R$.

Values of $\Delta \log R$ may be determined either by the obvious, and very laborious, process of calculating $\log R$ for each point of the heating curve, or by a much simpler alternative of plotting galvanometer deflexion directly and then calculating $\log R$ only for the two points which determine the temperature rise. Both procedures were found to give the same result.

Two features immediately emerged from the results. First, that owing to the very small temperature range over which the tests were made, i.e. very small change in $\Delta \log R$, a satisfactory linear relationship could be produced by plotting ΔR (or Δ scale reading) against heat input, thus making the computation of $\log R$ unnecessary. Second, the considerable importance of the bridge voltage was revealed. Fig. 3 shows a set of ΔR/heat input plots for a type $F$2311/300 thermistor at different bridge voltages, from which it will be seen that above a certain value of bridge voltage the response becomes non-linear, the degree of non-linearity increasing as the voltage rises. This latter effect is, in fact, to be anticipated and is undoubtedly due to the power sensitivity of the thermistor, for, when the resistance is altered by a change in ambient temperature, this produces a concomitant change in the power dissipated in the thermistor which again produces a further change in resistance. The magnitude of this further change will depend upon the power sensitivity of the thermistor (hence the reason for requiring a low power sensitivity) and on the total power dissipation within it; thus to reduce the effect to negligible proportions it is necessary to work with a very low power dissipation, i.e. a low value of bridge voltage.

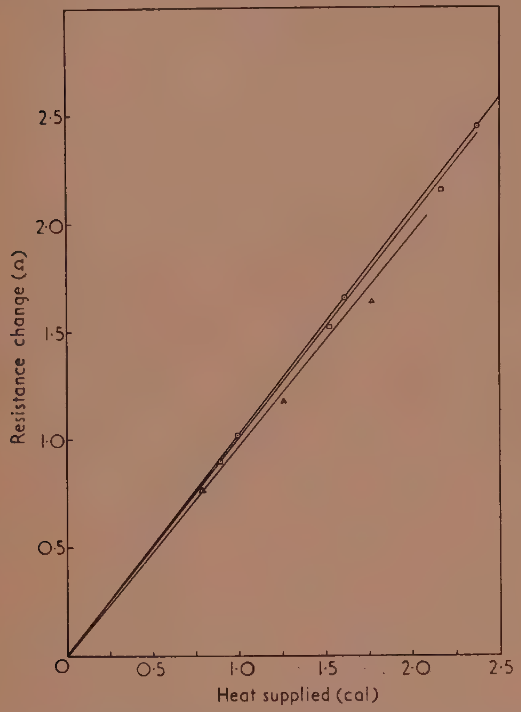


Fig. 3. Effect of bridge voltage on linearity of response thermistor, type $F$2311/300

⊙ = 1·0 V; ⊡ = 2·0 V; △ = 4·0 V

The high resistance type $F$1512/100 thermistor was found to behave in a similar manner to the low resistance type $F$2311/300 and, as may be seen in Table 2, the sensitivity achieved was some two to three times greater than with the low resistance type. However, by some readjustment of the circuit values and an increase in the working distance of the galvanometer (see Table 2) the sensitivity with the type $F$2311/300 thermistor was increased to a value considerably in excess of that previously achieved with the high resistance type. A further increase in the working distance of the galvanometer is probably not worthwhile as it would tend to unduly magnify instability in the galvanometer itself. The use of a more sensitive galvanometer, such as a Paschen type, is also probably not worthwhile since it would require elaborate mounting, and would thus destroy the simplicity and robustness of the present arrangement. The final decision between the high and low resistance type F thermistors is made on the grounds of stability as the accuracy obtainable is ultimately dependent on stability rather than sensitivity. Owing to the necessity for maintaining very high values of leakage resistance with the high resistance type, and the considerable difficulty experienced in so doing, it has been found, in fact, that the circuit containing the high resistance type is much less stable than the low.

Of the type A thermistors examined, the 500 000 Ω type proved to be totally unsatisfactory as the circuit was subject to even greater instability than with the 100 000 Ω type F. The figure given for its sensitivity in Table 2 is only approximate and it was not possible to check the linearity of response. The low resistance thermistor, type A 2321/100 (2000 Ω), was tested under the same conditions of bridge voltage as were found necessary for a linear response with thermistor type $F$2311/300 (2000 Ω), and was found to produce a non-linear response, though its sensitivity (Table 2) appeared to be higher. The non-linearity is presumably due to its much higher power sensitivity, and as nothing appeared to be

Table 2. *Conditions and sensitivities achieved with various types of thermistor using circuit in Fig. 5*

Thermistor type	*Bridge voltage (V)*	*Galvanometer working distance M*	$R_1^*(\Omega)$	$R_2^*(\Omega)$	$R_3(\Omega)$	$R_4^*(\Omega)$	$R_5(\Omega)$	$R_6(\Omega)$	*Response*†	*Sensitivity (cm/cal)*
F 2311/300	1	1	0	*R.B.*	2 000	2 000	5000	∞	*L*	4·1
(2000 Ω)	1·4	1	*R.B.*	2 000	10 000	10 000	0	∞	*L*	8·0
		2							*L*	16·0
F 1512	12	1	0	100 000	100 000	*R.B.*	0	20 000	*L*	9·1
(100 000 Ω)	16								*L*	11·5
	20								*N*	15·5
A 5513/100	20	1	0	500 000	100 000	*R.B.*	0	20 000	not examined	∼6
(500 000 Ω)										
A 2321/100	1	1	0	*R.B.*	2 000	2 000	5000	∞	*N*	∼6·2
(2000 Ω)										
A 1415/100	4·4	2	*R.B.*	10 000	20 000	20 000	0	∞	*L*	29·5
(10 000 Ω)	5·84								*N*	41·0

* *R.B.* indicates decade resistance box for balancing bridge.

† *L* indicates that plot of change in scale reading *versus* heat input was linear, *N* that this was non-linear.

gained over the corresponding type *F* it was not further examined.

However, the thermistor type *A* 1415/100, with a nominal resistance of 10 000 Ω was found to possess a high stability, providing due care was taken with insulation, and to be capable of a higher sensitivity than any of the types previously tested. The effect of bridge voltage on linearity of response is shown in Fig. 4, the circuit used being shown in Fig. 5.

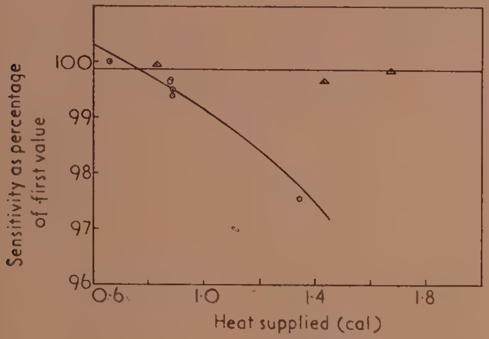


Fig. 4. Check on linearity of response of type *A* 1415/100 thermistor

Bridge voltage: △ = 4·40 V; ○ = 5·84 V

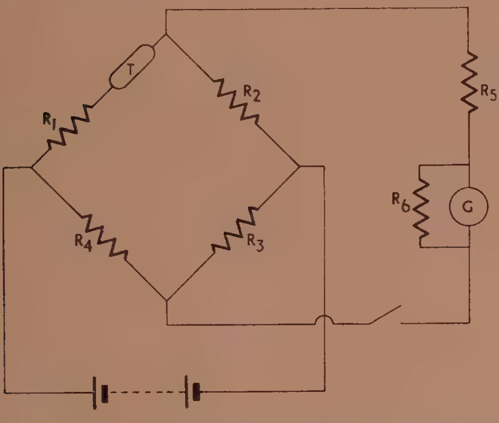


Fig. 5. Circuit used for examination of thermistors

T = thermistor
G = galvanometer Cambridge short period type 41127/2
coil resistance = 600 Ω
critical damping resistance = 25 000 Ω
sensitivity = 4500 mm/μA at 1 m
period = 4 s

In view of these results it was finally decided that the most satisfactory of all the types examined was the type *A* 1415/100, which provided a stability equal to that of the type *F* 2311/300, but gave approximately double the sensitivity previously achieved with the latter under the best conditions. This type of thermistor was therefore employed in the final form of the calorimeter. To avoid the necessity for elaborate scale calibration, a curved galvanometer scale was used (length 100 cm, radius of curvature 2 m) and carefully alined with the galvanometer, the working distance of which was adjusted to 2 m.

FINAL CHECK ON PERFORMANCE

Measurement of heat of solution of KCl. In order to provide a final check on the overall performance of the equipment some measurements have been made of the heat of solution of potassium chloride. Analar potassium chloride which had been dried for 48 h at 150° C and then stored over phosphorus pentoxide was used throughout. A quantity of from 10–30 mg was weighed into a thin glass bulb of 1 cm diameter which was then sealed in a flame and placed in the apparatus, the charge of water in the calorimeter being 35 gm. In carrying out a determination the procedure was first to perform a calibration run in which a known quantity of electrical energy was introduced, then the heat of solution run and finally a second calibration period. Any determination in which the calibration periods failed to agree was rejected. The heating periods were of 20–30 s and the temperature change appeared complete in about 2·5 min, which was approximately the time occupied by the thermal process in the heat of solution runs. Weighing errors are estimated as ±0·05 mg.

The results of four such determinations are given in Table 3.

Table 3. *Heat of solution of potassium chloride in water*

Potassium chloride	*Heat effect observed*			*N.B.S.**	*Error*
(mg)	*(J)*	*(kJ/mol)*	*Dilution*	*value*	*(%)*
30·375	−7·053	−17·31	4771	−17·39	−0·46
21·429	−4·986	−17·35	6764	−17·36	−0·06
17·433	−4·067	−17·39	8313	−17·34	+0·29
17·974	−4·218	−17·49	8063	−17·34	+0·86

* These figures are interpolated from the results in *Selected Thermodynamic Properties.* Circular 500 (Washington: National Bureau of Standards).

It is evident from these results that a precision of 1% is readily attainable. This error is estimated to be made up of ±0·2% weighing, ±0·3% error in determining the heat effect, the remainder ±0·5% being due to the heat effect occurring on breaking the glass bulb containing the sample. To obtain more accurate values it is essential to make a correction for the heat effect occurring on breaking an empty glass bulb. The bulbs used were of standard dimensions; the calculated heat effect for expansion of water vapour into a bulb filled with dry air is −0·04 J and can thus make an appreciable contribution to measured heat effects. However, there are other effects to be taken into account. These are the energy dissipated by the plunger used to crush the bulb and, more important, the release of strain energy in the glass of the bulb when it is shattered. The latter will lead to a heating effect and can neither be calculated nor easily made reproducible. For these reasons the heat of breaking of a bulb will be expected to show considerable variation, and may be either negative or positive, depending on whether the evaporation effect is more or less than the others.

A number of experiments carried out with empty bulbs showed variation from approximately −0·03 to +0·03 J with many values of approximately zero. From this it appears that any appreciable improvement in precision will be dependent on the evolution of a technique for making and handling bulbs which will yield more reproducible values for the heat of breaking. This problem is at present being studied.

ACKNOWLEDGEMENTS

It is a pleasure to express our thanks to Dr. W. J. Dunning of the University of Bristol, Dr. H. A. Skinner of the University of Manchester, and Dr. R. E. Richards of Lincoln College, Oxford, for much helpful discussion and advice. We are also greatly indebted to Mr. E. W. Pulsford of Electronics Division, Atomic Energy Research Establishment, for suggesting the timing method used.

REFERENCES

(1) Westrum, E. F. National Nuclear Energy Series Vol. 14B. The Transuranium Elements, paper 6–51 (New York: McGraw Hill Book Co. Inc., 1949).
(2) Skinner, H. A., and Pritchard, H. O. *J. Chem. Soc.*, p. 272 (1950).
(3) Greenhill, E. B., and Whitehead, J. R. *J. Sci. Instrum.*, **26**, p. 92 (1949).
(4) Hutchinson, E. *Trans Faraday Soc.*, **43**, p. 443 (1947)
(5) Zettlemeyer, A. C., Young, G. J., Chessick, J. J., an Healey, F. H. *J. Phys. Chem.*, **57**, p. 649 (1953).
(6) Hargreaves, M. K. *J. Chem. Soc.*, p. 1233 (1954).
(7) Bartell, F. E., and Suggitt, R. M. *J. Phys. Chem.* **58**, p. 36 (1954).
(8) Hutchinson, W. P., Pulsford, E. W., and White, A. G *J. Sci. Instrum.*, **31**, p. 420 (1954).

A superconducting modulator

By I. M. Templeton, M.A., D.Phil.,* Division of Physics, National Research Council, Ottawa, Canada

[*Paper received* 13 *April*, 1955]

A new type of d.c. amplifier for use at liquid helium temperatures, based on a magnetically modulated tantalum wire, is described. The input impedance is approximately $10^{-3}\,\Omega$, and noise figures down to approximately 2×10^{-11} V are fairly easily obtained. The application of this instrument as a null detector for the measurement of very small voltages in a liquid helium bath is described.

The measurement of small resistances and of small static voltages in general at low temperatures has been approached in two direct ways in recent years: firstly, with the galvanometer amplifier;(1) secondly, with the superconducting galvanometer.(2)

The galvanometer amplifier has the advantage of fairly rapid response and high input impedance, but has a limiting noise figure of about 10^{-8} V, set by the thermal noise from the primary galvanometer which is effectively included in the input circuit. There is also the disadvantage that connexions to the specimen under investigation have to be brought out of the helium bath with the inevitable accompaniment of fairly large thermal e.m.f.'s. Local vibration can effect the limiting noise figure to a certain extent.

The superconducting galvanometer works *in* the helium bath, and by virtue of its negligibly small input impedance can be made an exceedingly sensitive voltage measuring device. However, depending as it does on the motion of a delicately suspended magnet, it is very sensitive to vibration.

It is not generally appreciated that a *purely* a.c. method of measurement such as can be applied with considerable accuracy at room temperatures is quite inapplicable to pure metals at low temperatures. Let us consider, for instance, a typical specimen of copper wire, with a length of 20 cm and a cross-section of $0 \cdot 0003$ cm². At room temperature this will have a resistance of approximately $10^{-2}\,\Omega$, while at $4 \cdot 2°$ K it may be as low as $2 \times 10^{-5}\,\Omega$. The inductance of this wire, however, will remain unchanged at about $0 \cdot 3\,\mu$H. This means that at a convenient measuring frequency of approximately 1 kc/s, it will have a reactance of approximately $2 \times 10^{-3}\,\Omega$. It will thus be impossible to make any accurate measurements on such a specimen by purely a.c. methods at low temperatures.

For these reasons a "superconducting modulator" has been developed, whereby a section of a fine superconducting wire is "swung" into and out of the normal state by the application of an audio-frequency alternating magnetic field. A "d.c." component to the field is also required to hold the wire at the transition point. The modulated wire is connected i series with the (low resistance) source of e.m.f. and th primary of a miniature audio-frequency transformer *in th liquid helium.*

In this way the small static voltage is "chopped" and th resulting a.c. signal stepped up to a working impedance i the helium bath. There is little trouble from vibration, an none from thermoelectric effects on the output leads. Fro this point the signal is dealt with by fairly conventiona methods.

APPARATUS

The system which was actually devised is shown in Fig. 1 A tantalum wire $0 \cdot 002$ in. in diameter is used in the modu

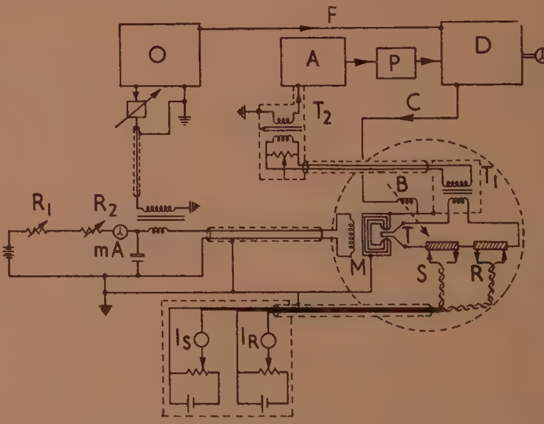


Fig. 1. Block diagram of circuit of superconducting modulator

A, variable gain amplifier; *B*, bucking coil; *C*, bucking signal; *D*, phase sensitive detector; *F*, reference signal; *M*, modulator; *mA*, 0–100 mA; *O*, 800 c/s oscillator; *P*, 800 c/s pass; *R*, comparison resistance; R_1, coarse resistance; R_2, fine resistance; *S*, specimen; *T*, tantalum wire; T_1, transformer 1 (50 : 1); T_2, transformer 2 (100 : 1); I_S, specimen current; I_R, comparison resistance current.

The circle formed by the broken line denotes the section of the circuit in liquid helium.

---

* National Research Laboratories Postdoctorate Fellow. Now at British Thomson-Houston Co. Ltd., Rugby.

ator, tantalum being chosen because of its small (60 gauss) ransition field at 4·2° K. Connexion is made to the ends f the wire by spot-welded pieces of nickel foil, and shorting s prevented by a thin coating of lacquer. The resistance of he modulated section of the wire in the normal state is bout 10^{-1} Ω. To avoid introducing any unnecessary esistance, the primary circuit is of lead wire where possible.

The transformer, which is very small, has a 0·02 in.^{2} Mumetal core, and the primary and secondary consist of two urns of lead and a hundred turns of copper, having impedances at the working frequency of about 4×10^{-3} and 0 Ω respectively. It is enclosed in a lead box to exclude xternal fields and stray field from the modulating coil.

The modulating coil itself, which consists of about a housand turns of fine enamelled copper wire, is wound on steel former and enclosed in a cylindrical steel case in such way that there is a minimum of external field, and the antalum wire (enclosed in a thin glass tube) is introduced xially (Fig. 2). The biased modulating current is obtained rom an 800 c/s oscillator and a 6 V accumulator as shown n Fig. 1.

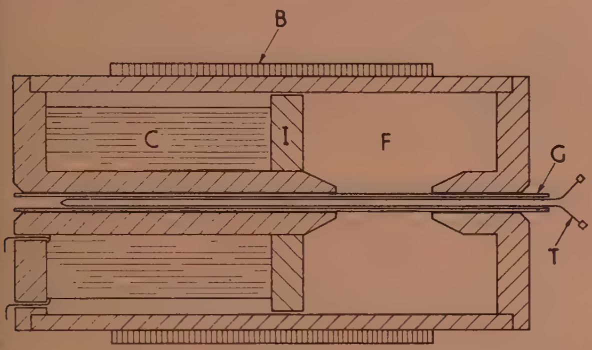


Fig. 2. Cross-section of modulator assembly (not to scale). The cylinder is approximately 5 cm long

B, bucking coil; *C*, coil; *F*, field gap; *G*, glass tube; *I*, insulator; *T*, tantalum wire.

Signal is taken from the transformer secondary *via* a creened twin wire to an audio-frequency amplifier having a arefully shielded and balanced input transformer with a tep-up ratio of approximately 100 : 1. From here the mplified signal is fed to a phase-sensitive detector which has n input circuit tuned to pass 800 c/s. The detector may be witched to examine signal components in phase and 90° out f phase with an 800 c/s comparison signal from the oscillator. t was found necessary to apply a certain degree of "bucking" n the helium bath to cancel out stray field from the modulator: uitable signals of variable amplitude and phase, derived rom the detector, may be fed to a coil wound on the outside f the modulator.

As a reference voltage source for the initial tests, a piece f copper wire previously measured on a galvanometer mplifier to be about 5×10^{-6} Ω at 4·2° K was used. By assing small currents through this (*via* separate contacts) it as found that with the amplifier at full gain and the modulating field adjusted for optimum conditions, half-scale deflexion n the centre-zero output meter corresponded to about $\times 10^{-9}$ V, with the noise level well below 1% of half scale, i.e. of the order of 2×10^{-11} V. The signal appears at 90° to the original phase of the modulating voltage: the reason for this is not at present quite clear since a simple treatment would predict direct phasing. Response of the meter depends on the circuitry of the detector: a time-constant of 0·1 s is at present in use. It should theoretically be possible to realize a lower noise-level since with the transformer ratios in use, noise from the first stage of the amplifier should be equivalent to about 10^{-12} V at the primary of the first transformer. However, such perfect matching is difficult to attain, and the present figure is considered satisfactory.

The modulator operates much as expected: with the modulation control set to give about 3 mA a.c. through the coil, and about 5×10^{-9} V on the reference source, the d.c. field coarse control is increased until the output meter shows a deflexion. The fine control is then adjusted for maximum deflexion to find the optimum operating point; at 4·2° K this is reached at about 26 mA d.c. Correctness of operation may be checked by reversing the current through the reference source when an equal reading in the opposite sense should be obtained.

Linearity appears to be quite good, but for accurate measurements it was decided to use the instrument as a null indicator. This may be done simply by connecting the source of voltage to be measured in series with the reference source, and varying the current through the latter to give zero reading.

USE OF INSTRUMENT

The instrument has been constructed primarily for measuring small thermoelectric potentials, particularly of the alkali metals at low temperatures, and also for examination of problems connected with a redetermination of the absolute scale of thermoelectric power. However, as an example of its performance compared with a galvanometer amplifier, we may quote measurements on a single crystal of copper which had a diameter of 3 mm and a resistance of 0·192 $\mu\Omega$ at 4·2° K. The residual resistance ratio of the crystal was $2{\cdot}60 \times 10^{-3}$. Measured at 4·2° K with the galvanometer amplifier, used as a direct reading instrument, the passage of a current of 1 A gave a scale deflexion of only 1·6 cm at the smallest usable feedback resistance (30 Ω). The observed noise was considerable so that the relative error was at least 10%. Measured with the modulator, used as a null indicator by comparison with a known resistance, the error due to thermal fluctuations was less than 1% at an intensity of 30 mA. As it is possible to use an intensity of 1 A, a similar crystal having a diameter of 1·7 cm could equally well be measured with an error of less than 1% due to thermal fluctuations.

ACKNOWLEDGEMENT

I wish to thank Dr. J. P. Jan for supplying the data on measurements of a copper single crystal.

REFERENCES

(1) MacDonald, D. K. C. *J. Sci. Instrum.*, **24**, p. 232 (1947).

(2) Pippard, A. B., and Pullan, G. T. *Proc. Cambridge Phil. Soc.*, **47**, p. 811 (1952).

Dosimetry of X- and γ-rays by alkali-halide crystals containing U-centres

By W. G. Burns, B.A., Ph.D.,* and R. Lockyer, B.Sc., F.R.I.C., Hilger and Watts Ltd., London, N.W.1

[*Paper received* 31 *March*, 1955]

A crystal dosimeter is described. The sensitive element is a crystal of potassium chloride containing potassium hydride in solid solution at a concentration of $5\cdot5 \times 10^{18}$ molecules potassium hydride per cm^3, and this becomes coloured due to the formation of the F-band on irradiation. The colour is stable in the dark up to 50° C, and fades in the light sufficiently slowly for a reasonably accurate estimation of the dose to be made. The preparation of the material and tests on its sensitivity, temperature dependence, energy dependence and rate of dosing, are described. Using a spectrophotometer, doses from ten to many thousand röntgen of γ-rays have been measured. This type of dosimeter has the advantage over the radiophotoluminescent type that a visible coloration is produced enabling doses of 75 r and upwards to be estimated roughly without a special reader. A simple, battery-operated reader enabling field measurement of doses from 20 to 600 r has been made. Its characteristics make the dosimeter very suitable for a personnel flash dosimeter.

The effect of γ- and X-rays on pure crystals of alkali halides is to produce mainly Compton scattered electrons and photoelectrons (pair production is important only at high energies) which in secondary ionizations ultimately remove electrons from chloride ions. Some of the electrons become trapped at negative ion vacancies to form F-centres, and eventually the holes necessarily produced in conjunction with these are stabilized by becoming trapped, for instance to form positive ion vacancies sharing five instead of the normal six electrons. This type of vacancy gives rise to the V-bands described by Casler, Pringsheim and Yuster,(1) and by Alexander and Schneider.(2) The coloration produced is not useful for dosimetry since it is not reproducible, varying from one part of a crystal to another,(1) it fades quickly in the light, especially just after irradiation before the positive holes are stabilized,(2) and even in the dark the coloration fades fairly quickly. The speed of fading in the dark increases progressively in the order(1, 3) lithium fluoride, sodium chloride, potassium chloride and potassium bromide.

If, however, a colourless crystal of potassium chloride is prepared as described below, containing in solid solution a small proportion of potassium hydride (about 0·1%), the following differences are observed:

(*a*) The optical density of the F-band produced on irradiation is greater by a factor of about 100 than with the pure substance and is reproducible.

(*b*) In the light the fading is slow.

(*c*) In the dark there is no fading up to a temperature of over 50° C. These observations are perhaps connected with the easier removal of an electron from the H^- ion than the Cl^- ion, and a smaller tendency for the hole and trapped electron to neutralize each other than in the pure crystal. They indicated that this type of crystal might be useful as a dosimeter and caused a careful investigation of the relevant properties to be undertaken.

The preparation of alkali halide crystals containing hydride is described by Hilsch,(4) and their properties are reviewed by Mott and Gurney.(5) The H^- ion causes a very strong absorption band (at the concentrations used here) centred at 214 mμ in potassium chloride (U-band), and when illuminated with light in this band F-centres are formed, but only at the very surface, owing to the strong absorption. With X- and γ-rays the distribution of the colour centres is more uniform with increasing energy of the radiation. The effect of X-ray on potassium bromide/potassium hydride crystals of mor than one potassium hydride concentration has been describe by Martienssen and Pick.(6) These workers observed th fall of the U-band as well as the rise of the F-band on irradiation and they observed a saturation effect. This effect wa not observed in our work owing to the high concentration o U-centres (of the order of 5×10^{18} per cm^3) and the relativel low doses in which we were interested.

PREPARATION OF THE MATERIAL

Crystal growing. Large pure crystals 9 in. in diameter an 5 in. deep were prepared by the Kyropoulos(7) method fro the molten Analar salt (by British Drug Houses Ltd. an Hopkin and Williams Ltd.) using a seed crystal held in water-cooled nickel chuck.

Crystal processing

(*a*) *Potassium treatment.* Crystals containing potassiu hydride in solid solution (i.e. U-centres) were produced in two-stage process; in the first stage the crystals were impregnated with potassium, and in the second stage wit hydrogen.

The preparation of crystals impregnated with potassiu has been described by Rogener.(8) In our work crystals wer cleaved to the desired size and placed in a "bomb" with piece of unpurified potassium metal, separated from th crystals by a nickel or copper gauze baffle. For the bom any vessel which will remain tight under the conditions of th experiment (700° C and a few atmospheres pressure includin one atmosphere of potassium vapour) will suffice. Our fina design was in the form of a heat-resisting steel tube 12 in. $1\frac{3}{4}$ in. inner diameter × $2\frac{1}{4}$ in. outer diameter with screwe heat-resisting steel plugs, the seal being made by the pressu of a knife-edge in the steel against a softened copper gaske The bomb was heated in a silica tubular furnace 4 in. diameter × 30 in. long, using a Multelec controller (by G. Ke Ltd.) which kept the temperature at the control point consta to ±3° C. Temperatures used were 680–710° C to obtai crystals with the maximum possible potassium content, an with our size of crystal (7 × 7 × 54 mm) the time require at these temperatures was four hours.

(*b*) *Hydrogen treatment.* This was done at 2500 lb/in and 700° C. The bomb used was of the conventional typ described by Tongue[(3)] and was in the form of a heat-sisting steel cylinder 3 in. outer diameter with a hole 7 in. ep by 1½ in. diameter, the blind end of the hole being lined.

---

* Now at Atomic Energy Research Establishment, Harwell, Berks.

n the usual run, the potassium-treated crystals were put o the bomb which was then sealed and about 1500 lb in.^{2} hydrogen introduced. The bomb was then heated to ° C.; the external control point required twenty minutes reach 700° C. and was constant to ±3°, for the remaining enty minutes of the run, and during the last twenty minutes pressure was kept constant at 2500 lb in.^{2} by releasing excess pressure caused by the rise in temperature.

The resultant crystals contained potassium hydride in solid ution. The concentration was measured by measuring the drogen evolved on solution of a known mass of crystal.[(4)] d was found to be 5·5 × 10^{18} potassium hydride molecules r cm.^{3}

TESTS ON THE MATERIAL

Dosage measurements. These were at first done roughly calculation from the ^{60}Co source strength and distance m the source. This method was later shown to be ficiently accurate by the standardizing of crystals by nization chamber dosage measurements at the National ysical Laboratory.

Effect of dosage. Fig. 1. The effect of dosage is to duce the well-known F-band in potassium chloride with

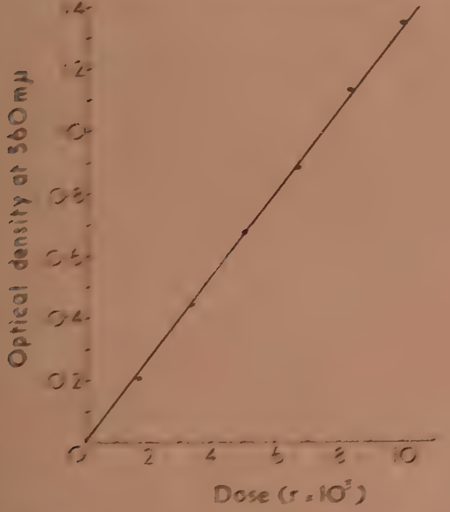


Fig. 1. Effect of dose on optical density at F-band maximum. Crystal No. HB 178. Thickness 3·5 mm. Dose rate 790 r/min of ^{60}Co γ-rays

k optical density proportional to the dose. Measurements re made from ten to several thousand röntgens, which s thought to be the region of interest, and over this range absorption constant K at the F-band maximum was portional to the dose r to within 5% for a given crystal. may be defined by $I/I_0 = 10^{-Kl}$, where I and I_0 are the nsmitted and incident intensities and l is the path length entimetres and its value was found to be 3·5 × 10^{-4} cm^{-1} unit dose.

eproducibility. The maximum variation from the mean sitivity of crystals taken from different parts of the bomb a single run and taken at random over a large number runs (about 30) done under the same conditions was ±13%.

Reciprocity. The rate of dosing was found to have no effect on the colour produced with dose rates of from 1 to 9000 r/min of ^{60}Co γ-rays and with dose-rates obtainable with the linear accelerator at Harwell.

Fading. Fig. 2 shows the rate of fall of the peak absorption of dosed potassium chloride and potassium bromide crystals containing U-centres under illumination. In the first two minutes the peak has fallen 10%, so that the time taken for a visual assessment of the dose (which can be made in 15 s) can be made short enough to cause a negligible fading. The fading during measurement on the Uvispek used for spectrophotometric measurements and on the readers described later can also be made negligible.

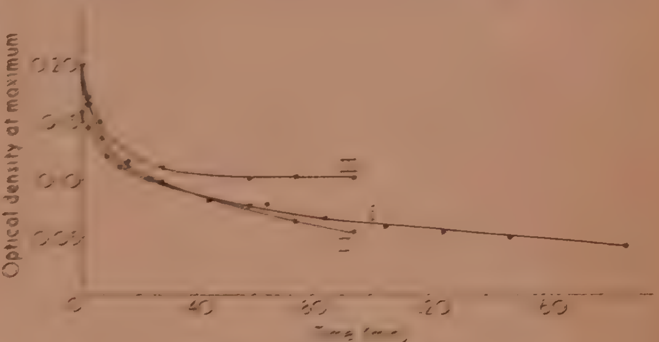


Fig. 2. Fading in light

Curve I, fading of potassium chloride potassium hydride; Curve II, fading of potassium chloride potassium hydride, dose 2760 r; Curve III, fading of potassium bromide potassium hydride, dose 2760 r ^{60}Co rays. Crystal thickness 2 mm. Simultaneously exposed to 80 W fluoresent tube at 5 ft.

Prolonged exposure to a strong light restores the crystal to its original condition, and one crystal was given five successive doses of 1000 r, being completely faded between doses, and each time on dosing gave the same absorption curve to within 3%.

Temperature dependence. The effect of temperature is shown in Fig. 3. An increase in temperature of 25° C causes a 15% increase in sensitivity.

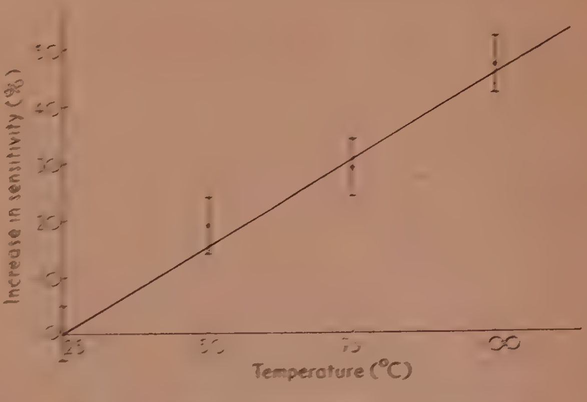


Fig. 3. Effect of temperature on sensitivity

Storage. The sensitivity of the undosed crystal material has remained constant over two years when kept at room temperature, and the system would be expected to be perfectly stable. To avoid deterioration of the surface, the crystal must of course be protected from moisture.

The colour of the dosed crystals has remained constant for a period of eighteen months, kept in the dark at room temperature. It also seems to be stable at 50° C, for no change was observed in four weeks at this temperature, but in four days at 100° C a 16% drop in peak optical density was recorded.

Energy dependence. The effects of radiation of different energies were measured. Crystals 6 × 6 × 10 mm were irradiated from the side, and measured along the axis with a Uvispek using a small beam of light 1 mm wide × 2 mm high. The optical density was measured at three points along a diagonal, and so a rough graph of optical density against distance from the exposed face could be drawn. Fig. 4 shows the absorption constants for distances from the exposed face corresponding to (*a*) the centre of a 6·25 mm thick crystal, (*b*) the centre of a 4·5 mm thick crystal and, by extrapolation, the surface. Based on these measurements a shield of 1 mm tin to cut down the peak in the response curve has been recommended.

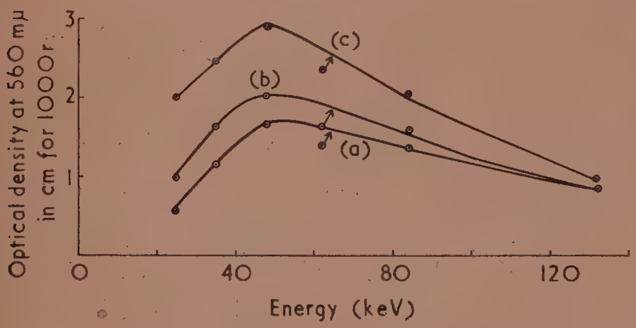


Fig. 4. Energy dependence. Value at 1·2 MeV is 0·26 (crystals processed at 2000 lb/in.^{2} and not of full sensitivity)

INSTRUMENTS

Self-reading dosimeter. As the coloration is visible, a simple self-reading device is possible, and this is shown in Figs. 5 and 6. To enable a distinguishable colour to be seen at 75 r, the crystal has to be 2 in. long, and in the instrument is protected by glass plates cemented to the ends. It is surrounded at the top by a Diakon moulding made from a specially matched powder which, when viewed along the axis, presents colours corresponding to 75, 150 and 300 r, in truncated quadrants surrounding the square crystal. The space not taken up by the step moulding is filled by a piece c Perspex in the form of a cylinder with a square hole. Th crystal and its plastic surrounding pieces are contained in a aluminium tube and this unit can be removed and put int the reader described below for a more accurate assessmen of the dose. The lens system enables one to see a magnifie image of the crystal and its surrounding comparison colours the end caps are light-tight and must be kept shut when th instrument is not in use, and the whole instrument is of convenient fountain-pen shape.

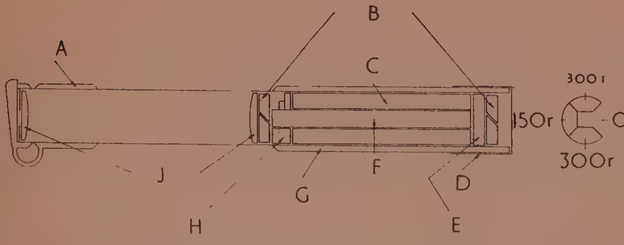


Fig. 5. Self-reading dosimeter

A, polythene captive end cap; *B*, retaining rings; *C*, clear moulding; *D*, end cap; *E*, diffusing screen; *F*, crystal; *G*, tin radiation shield; *H*, coloured step moulding; *J*, lenses.

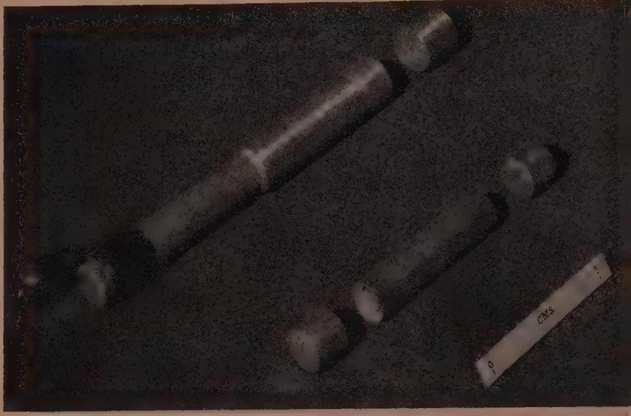


Fig. 6. Self-reading and sealed dosimeters

Sealed dosimeter. Fig. 6. This merely consists of th crystal with its radiation shield held centrally along the axi of the outer tube, with end caps to keep out the light whe not being read.

Readers. Figs. 7 and 8. The reader is a simple colori meter which has to measure the absorption of the F-ban produced in the crystal by irradiation. There are two mai difficulties in the design. One is that the crystal has a initial variable slight cloudiness, and the other is the fadin during measurement, which means that a small light flu must be used, and, therefore, a sensitive detector. Th difficulty of the cloudiness is overcome by measuring th difference in the transmission of the dosed crystal for ligh on either side of the F-band (transmitted by a minus gree filter) and light at the centre of the F-band (transmitted b a green filter).

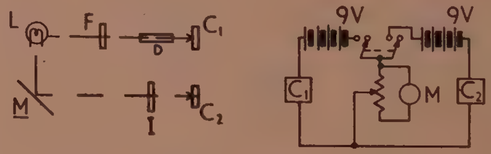


Fig. 7. Battery-operated reader

L, lamp; *F*, movable filter; *M*, mirror; *I*, adjustable diaphragm; *D* dosed crystal; C_1, C_2, photoconductive cells; *M*, micro-ammeter.

There are two photocells connected in opposition, and i the light path to one is the crystal and a movable filter disk and in the path to the other is an adjustable diaphragm. Th minus green filter is first put in the light path to the crysta and the diaphragm adjusted to give zero deflexion of th meter. The light in the first beam is then cut off and th ensitivity of the meter adjusted to give full scale deflexion. he green filter is then interposed and the out-of-balance urrent shown on the meter is a measure of the dose. The eter is calibrated to read directly in röntgens. The light ource is a 5·5 V bulb run from two dry batteries. The nergy available in the F-band is therefore small, calling for xtreme sensitivity in the photocells. The Hilger–Schwarz hotoconductive cells possess the necessary sensitivity and erive their operating current from two standard grid bias atteries. Using these readers doses from 20 to 600 r have een measured.

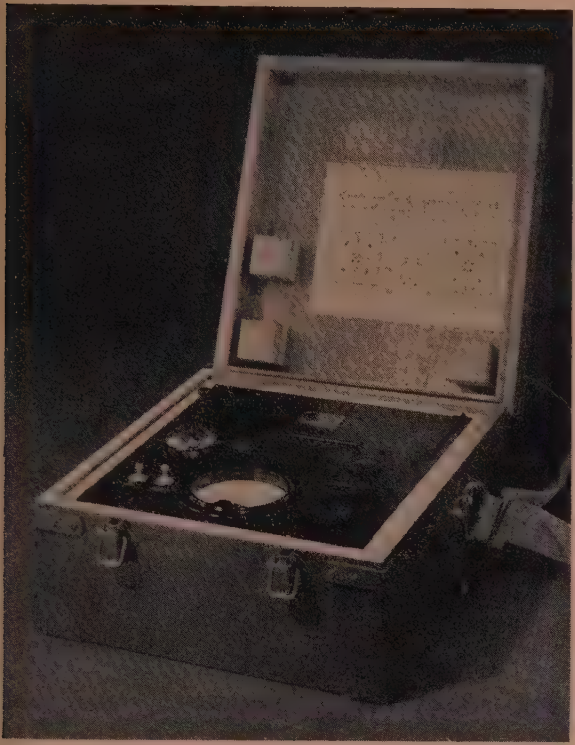


Fig. 8. Battery-operated reader

A visual reader has also been designed and made, in which here are two light paths, one through the crystal and the ther through a wedge of Diakon moulded from the special owder mentioned above. In the eyepiece a divided field is een and to read the dose of the crystal under examination a ever is adjusted which moves the position of the Diakon edge, in the beam, until a colour match is obtained. The osition of the lever is calibrated in dosage. For this reader longer path length and wider aperture is required than for e photoelectric ones, and a larger crystal 4·5 × 14 × 19 mm^3 used in which the light traverses the longest dimension vice, being reflected at one end.

CONCLUSIONS

The tests described above show that crystals containing U-centres have suitable characteristics for γ-ray flash dosimetry, and suitable instruments can be made for this purpose. The main technical disadvantage they suffer from is that, on exposure to light, the colour fades, but this can be overcome by making the time of measurement sufficiently short and providing the crystal with a cover which will remain light-tight between exposure and measurement.

It has been pointed out$^{(11)}$ that, for some purposes, a self-reading instrument is desirable, and this is possible with the self-reading crystal dosimeter. If a sealed dosimeter is required the measurement of dose can be done on a simple battery-operated and easily portable reader.

ACKNOWLEDGEMENTS

We wish to express our thanks to Dr. Denis Taylor and Contracts Branch, Atomic Energy Research Establishment, Harwell, for permission to publish this paper, to Dr. A. C. Menzies, Controller of Research, and Mr. J. W. Perry, Head of Applied Optics, Hilger and Watts Ltd., and to Mr. R. B. Owen, Atomic Energy Research Establishment, Harwell, for encouragement and advice, and to Messrs. A. R. Hall and T. Parrish, of Hilger and Watts Ltd., for technical assistance. We also wish to thank Dr. Aston of the National Physical Laboratory for assistance with the X-ray dosing, and Dr. Wild of the Atomic Energy Research Establishment, Harwell, for use of the kc ^{60}Co source.

REFERENCES

(1) Casler, R., Pringsheim, P., and Yuster, P. *J. Chem. Phys.*, **18,** pp. 887, 1564 (1950).

(2) Alexander, J., and Schneider, E. E. *Nature* [*London*], **164,** p. 653 (1949).

(3) Alger, R. S. *Laboratory for Insulation Research,* M.I.T. Technical Report No. XV (1949).

(4) Hilsch, R. *Ann. Phys.* [*Leipzig*], **23,** p. 407 (1937).

(5) Mott, N. F., and Gurney, R. W. *Electronic Processes in Ionic Crystals* (London: Oxford University Press, 1948).

(6) Martienssen, W., and Pick, H. *Z. Phys.*, **135,** p. 309 (1953).

(7) Kyropoulos, S. *Z. Anorg. Allgem. Chem.*, **154,** p. 308 (1926); *Z. Phys.*, **63,** pp. 11–12, 849 (1930).

(8) Rogener, H. *Ann. Phys.* [*Leipzig*], **29,** p. 386 (1937).

(9) Tongue, H. *The design and construction of high pressure chemical plant* (London: Chapman and Hall Ltd., 1934).

(10) Burns, W. G., and Williams, T. F. *Nature* [*London*]. To be published.

(11) Taylor, D. *Ingenieur*, No. 37, p. 55 (1953).

Laboratory and workshop notes

A simply constructed electron-optical bench

By W. Fishwick, M.A., Ph.D., Engineering Department,
University of Edinburgh

[*Note first received* 26 *July*, 1954, *and in final form* 24 *March*, 1955]

The electron-optical bench described has been in use for some years for research and demonstration. The main evacuated section is constructed from industrial Pyrex pipe which is thick-walled, robust and easily obtainable. This pipe is manufactured with flared end sections and there are standard clamping rings available which can be used to fix end plates to the pipe sections or to clamp it to the pumping trolley. A shallow groove is moulded into the flared ends and by choosing an O-ring to fit this groove, good vacuum joints can be made in the usual way.

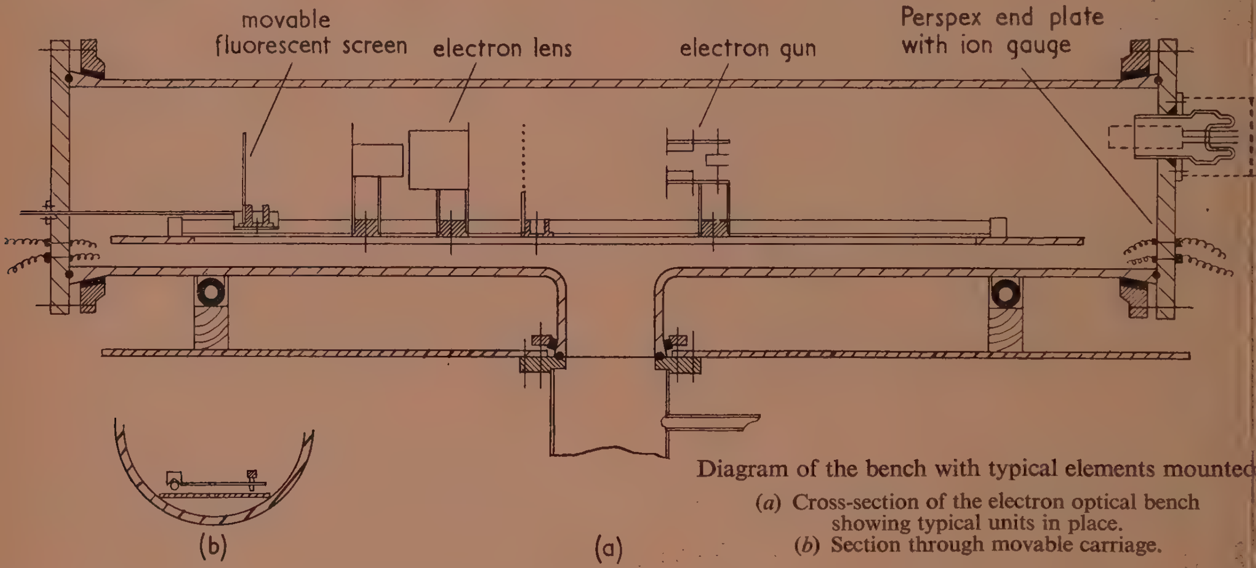


Diagram of the bench with typical elements mounted

(*a*) Cross-section of the electron optical bench showing typical units in place.
(*b*) Section through movable carriage.

The construction of the system is shown in the figure. A large horizontal Pyrex tube is supported by a centrally-placed side tube which connects it to the inlet of the high vacuum valve leading to the pumps. The Pyrex tube T-section is a standard section (manufactured by J. Jobling and Co., Ltd.). For most purposes the horizontal tube is 3 ft long and 6 in. internal diameter, but many other standard sections can be fitted. It is convenient to always use a flanged tube of 3 in. internal diameter as pump connexion. The inlet flange of the high vacuum side cut-off valve is flush with the table top of a trolley. Beneath the table top and mounted rigidly to it is the valve and a type 203A pump [by W. Edwards and Co. (London) Ltd.] using Apiezon B oil. On the baseplate of the trolley is the backing pump which is on flexible mountings and connected by a flexible tube to the vapour pump. A standard industrial clamping ring is used to compress the side tube on to an O-ring in a suitable groove in the valve flange. The ends of the main horizontal tube are sealed by Perspex disks, 0·5 in. or 0·625 in. thick. These are grooved to support an O-ring mating with the groove in the tube end. The Perspex disks carry electrical connexions, and if required, sliding rod Wilson seals for the manipulation of electrodes on the bench. The trolley is constructed out of Dexion and Duralumin sheet.

The bench itself consists of a slotted Duralumin plate 32 × 4 × 0·25 in. The central slot is used to bolt dov electrode systems or insulating blocks which carry electrod Alternatively, these blocks can be mounted on a moval carriage which is guided by a brass rail and can be moved fro outside. The baseplate rests on the glass and is norma connected to the end plates by electrical connexions on The insulating blocks are made from Perspex or from fir pyrophyllite (machined before firing) and can carry up four simple electrodes, or a cathode-ray tube gun, etc.

For some experiments the apparatus can be mounted on Perspex end plate, of which several are available, and t system used as a convenient pumping unit. One of the e plates carries a thermionic ion gauge.

With the largest tube described above, the volume to pumped out is about 20 l., and the superficial area abo 5500 cm^2. The pump has a speed of 50 l./s and an ultima vacuum of 5 × 10^{-6} mm of mercury so it is essential to cle the glass thoroughly, and advisable to outgas the glass wrapping with asbestos insulated heating tape, and to ba for an hour or so at 250° C. A short bake-out enables vacuum of better than 10^{-5} mm of mercury to be obtain easily. A liquid air trap is incorporated, but for ordina optical experiments is not necessary.

Vibrations are liable to be transmitted from the backi pump and motor to the components on the bench, and interfere with such measurements on a fluorescent screen might be made by a travelling telescope mounted outs the trolley. The main frequency of vibration is about 15 With auxiliary supports between each end of the main ho zontal tube and the trolley table, the maximum vibratio amplitude noted on the bench was ±0·07 mm. Witho these supports, which are rubber pads on wood blocks, amplitude is doubled.

The apparatus is suitable for many types of electr optical experiments and compares favourably in simplic with other systems which have been described.(1–4) It is suitable for magnetic lenses as in the case of one such system

REFERENCES

(1) Nicoll, F. H. *Proc. Phys. Soc.* [*London*], **50**, p.
(1938).

) REISNER, J. H., and PICARD, R. G. *Rev. Sci. Instrum.*, **19**, p. 556 (1948).
) BOERSCH, H. *Z. Phys.*, **130**, p. 517 (1951).
FERT, C. *C.R. Acad. Sci.* [*Paris*], **252**, p. 2085 (1951).
) MARTON, L., MORGAN, M. M., SCHUBERT, D. C., SHAH, J. R., and SIMPSON, J. A. *J. Res. Nat. Bur. Stand.*, **47**, p. 461 (1951).

Preparation of copper-constantan thermocouples

By E. F. KIERNAN, U.S. Navy Electronics Laboratory, San Diego 52, California, U.S.A.

[*Note first received* 7 *September, and in final form* 20 *December*, 1954]

making copper-constantan thermocouples suitable lengths each type of wire having diameters of 0·001 in. were epared by removing any insulation and oxide coating from 2 in. section near one end. To join the wires preparatory welding, the following arrangement was used. A sheet paper was fastened to a flat surface (12 × 12 × ¼ in. akelite) by narrow strips of masking tape placed diagonally ross the corners. Two pieces of brass, 1 × 3 × $\frac{1}{64}$ in., with nooth edges and rounded corners, were fastened near the ntre of the paper with strips of masking tape across the iddle of the short dimension of the strip. The pieces were ositioned with the longer edges parallel and the adjacent nds opposite and approximately 1¼ in. apart. One brass rip had the adjacent flat end surface polished for approxiately ½ in. with very fine emery cloth to remove the oxide. n insulated, stranded, copper wire conductor was soldered the other end. Three pieces of masking tape, about × ¼ in., were fastened to the brass strips in the following ay. A strip of tape was fastened across each of the adjacent nds of the two brass strips (*A* and *B*, Fig. 1) by pressing nly on a ⅛ in. section of the tape in the centre so that the nds of the tape curled up and cleared the brass. The tape ould not touch the outer area on the end of the polished rass strip as the film of adhesive left on the brass will prevent e wires to be placed there from making good electrical ontact. The third piece of tape was similarly fastened to e polished brass strip near the stranded lead. Each thermoouple wire was fastened to the brass strips by placing one d under the tape on the end of the unpolished brass strip 3, Fig. 1), parallel to the longer dimension and approxiately ⅛ in. in from the long edge, the wire extending in the irection of the polished strip. The tape was pressed down rmly to anchor the wire. Each wire was carried diagonally ross the space between the adjacent ends of the brass rips and anchored to the polished strip by means of the ther two strips of tape. The two wires, thus mounted, crossed in the centre of the space between the adjacent ends of the brass strips. The unpolished brass strip was unfastened from the paper sheet by removing the tape across its centre. The brass was then carefully picked up in the fingers, rotated twelve to eighteen full turns about its longer axis, and carefully replaced in its original position on the paper sheet. The unpolished brass strip was separated from the twisted wires by cutting the wires with a sharp knife near the end of the twisted portion. The polished strip with the twisted wires mounted on it was then released from the paper sheet by cutting through the masking tape along each side of the brass. The brass strip served as a convenient handle to manipulate the twisted wires during the welding process and also afforded a good electrical connexion to both wires.

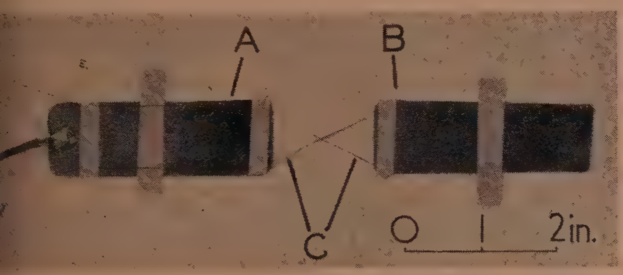


Fig. 1. Photograph showing construction of thermocouple and brass strips

To weld the wires together a heavy duty 22·5 V radio "B" battery (or equivalent), one 50 Ω rheostat, a small cup for containing mercury, and the necessary connecting wires were used. The cup used was a metal screw cap from a small bottle with a brass angle soldered to the bottom of the cap. During welding it was half-filled with mercury and clamped in a small vice. The mercury was covered with a layer of light oil to exclude air from the welding arc. The conductor from the polished brass strip was connected to the plus terminal of the battery, and a conductor, fastened to the vice by a small C clamp, was connected, in series with the rheostat, to the other terminal. The polished brass strip was held in one hand and slowly lowered until the end of the twisted pair came into contact with the mercury. A bright arc was produced, together with a sharp hissing sound, when the polarity of the battery was correct and the rheostat was properly adjusted. Excessive current produced too much metal at the weld.

A binocular microscope (×30) was used to inspect the wires and welds and to enable the manipulator to properly view the operation of removing the twist in the wires up to the weld. This latter operation was accomplished by placing the welded wires on the glass stage of the microscope with the weld positioned in the centre of the field of view; the wires were slowly pulled apart by pressing each down against the glass with a finger while at the same time moving the fingers in opposite directions. If the weld is good and care is exercised, the twist can be removed right up to the weld. The kinks left in the wires were ironed out by sliding the end of a tooth-pick over the wire while the weld was clamped to the glass with another tooth-pick.

To ascertain the "rise time" immediately after a couple was immersed in a hot oil bath (120° C; cold junction at

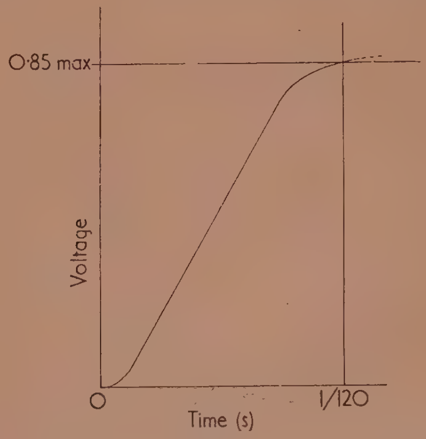


Fig. 2. Curve of voltage against time for thermocouple

approximately 20° C); use was made of a cathode-ray oscilloscope with a direct coupled pre-amplifier. With single sweep and a long persistent screen, a large number of visual observations were made of the voltage rise. A composite sketch of the screen trace is shown in Fig. 2.

A beam current stabilizer for an X-ray generator

By R. G. Stone, B.Sc., A.R.I.C., Department of the Government Chemist, London, W.C.2

[*Note first received* 30 *September*, 1954, *and in final form* 17 *January*, 1955]

The long-term stability of the beam current in an X-ray generator was found to be insufficient for use with a Geiger counter diffractometer. Changes of current are caused by heating of resistance networks, slight fluctuations of gas pressure in the continuously evacuated tube and changes line voltage. This stabilizer uses the d.c. potential across resistor placed in series with the beam current circuit control the current heating the X-ray tube filament. similar principle was used by Lees and Armitage.*

In the present circuit amplification has increased the sens tivity of control and the controlling thyratron carries on the marginal current necessary for stabilization. At workin conditions of 20 mA beam current and 28 kV target potentia with the stabilizer out of circuit, a 10 mA change in inp current to the X-ray set filament transformer causes a 2·5 m change in beam current. When the stabilizer is operatin in shunt with this transformer the resultant change in bea current is reduced to 0·06 mA. The effect of stabilization the random variation of beam current is shown in the tra

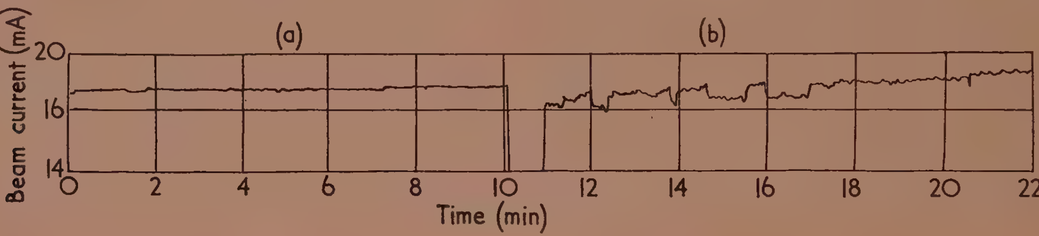


Fig. 1. Beam current fluctuations

(*a*) With stabilizer in circuit; (*b*) without stabilizer.

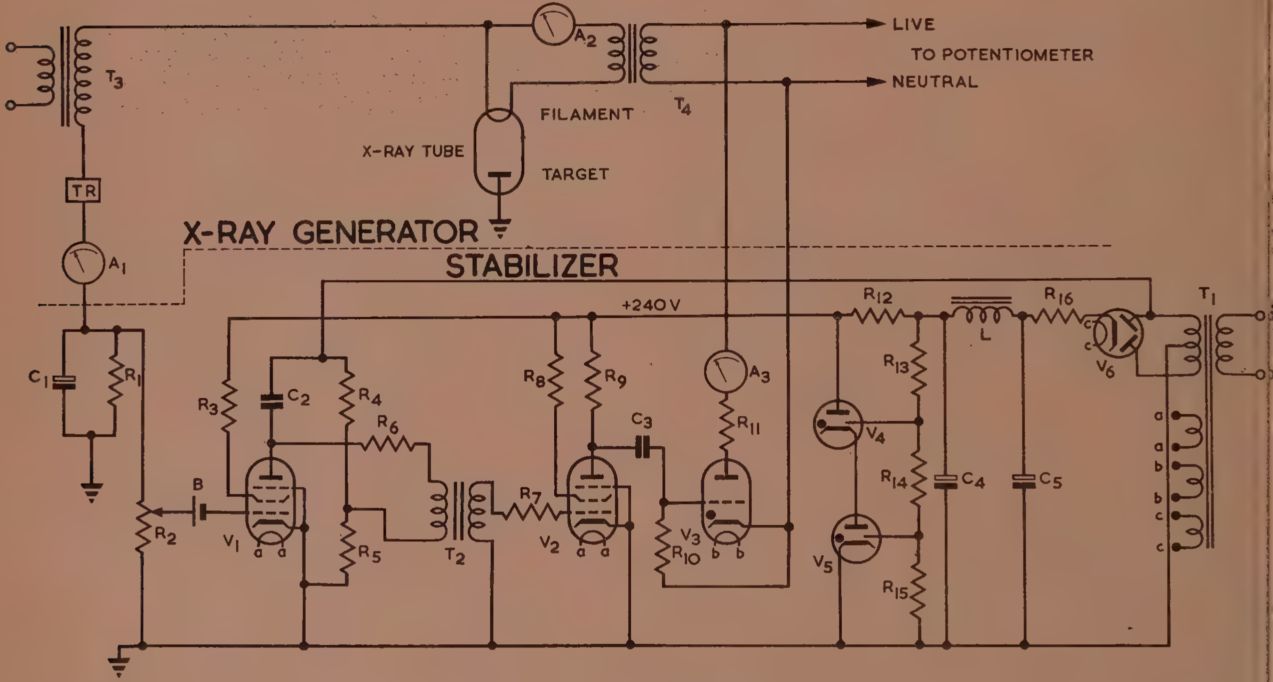


Fig. 2. Current stabilizer circuit

R_1 = 1 kΩ, 5 W, w.w.
R_2 = 0·25 MΩ potentiometer
R_3 = 56 kΩ, ½ W
R_4, R_5 = 22 kΩ, 2 W
R_6 = 2·7 kΩ, 1 W
R_7 = 33 kΩ, ½ W
R_8 = 22 kΩ, 1 W
R_9 = 47 kΩ, 1 W
R_{10} = 22 kΩ, ½ W
R_{11} = 50 Ω, 10 W
R_{12} = 6 kΩ, 5 W, w.w.
R_{13} = 10 kΩ, 1 W
R_{14} = 33 kΩ, 1 W
R_{15} = 68 kΩ, 1 W
R_{16} = 38 Ω, 1 W, w.w.

C_1 = 50 μF, 50 V
C_2 = 0·1 μF, 500 V oil-filled paper
C_3 = 1 μF, 350 V paper
C_4 = 16 μF, 450 V
C_5 = 8 μF, 450 V

V_1, V_2 = SP61
V_3 GT1C thyratron
V_4, V_5 = S130 stabilizer
V_6 = APV4 rectifier

TR = overload trip in generator
A_1 = beam current milliammeter in generator
A_2 = filament current ammeter in generator
A_3 = 0·5A thermocouple ammeter

B = 15 V dry battery B144 Ever Ready

T_1 = 350–0–350 V, 80 mA mains transformer
T_2 = intervalve transformer ratio 1: 3
T_3 = h.t. transformer in generator
T_4 = X-ray filament transformer in generator

L = smoothing choke 20H

---

* Lees, C. S., and Armitage, M. D. *J. Sci. Instrum.*, **27**, p. 3 (1950).

roduced by a Tinsley recording milliammeter in Fig. 1. luctuations and drift are both reduced by a factor of ten. he filament heating transformer in the generator is fed rom the a.c. supply by a resistance potentiometer network. he current taken by the primary of this transformer at a eam current of 20 mA and 28 kV target potential is about ·6A; a GT1C thyratron, placed in shunt across the primary inding, controls this current by means of a square wave of ariable phase on its grid. This phase variation is a function f the d.c. potential obtained from the beam current. The ircuit has been adapted from that of West and Partington.*

In Fig. 2, R_1C_1 produce a positive d.c. potential proporional to the beam current. Battery B provides a reference oltage source and backs off the positive d.c. signal leaving a egative d.c. bias on the grid of V_1. V_1, C_2, R_4 and R_5 form bridge which feeds V_2 with a wave of variable-phase conrolled by the bias on V_1. V_2 is a square-wave generator, he output of which is applied to the grid of the thyratron V_3. he anode of this valve has a sinusoidal voltage applied to it nd conduction depends on the phase difference between grid nd anode. In practice a control range of 120° can be btained. Thus an increase of beam current causes increased onduction by the thyratron and a consequent reduction of ilament current in the X-ray tube. Mains connexion to the ransformer T_1 may have to be reversed to ensure correct unctioning of the circuit. A thermocouple ammeter A_3 egisters the by-pass current which is set to approximately ·2A by the panel-mounted potentiometer R_2. Although he original filament control on the X-ray set and R_2 are nterdependent, no difficulty has been found in setting up the equired conditions. The neutral side of the filament transormer is connected to the cathode of V_3. The stabilizer ircuit must be switched on and allowed to warm up before ower is supplied to the filament transformer. This is nsured by appropriate connexion in the switching sequence f the X-ray generator. It is proposed, at a later date, to perate the stabilizer by a voltage derived from an ionization hamber or Geiger counter monitoring the incident beam.

The author wishes to thank the Government Chemist for ermission to publish this note.

* West, J. C., and Partington, D. K. *Electronic Engng*, **25**, . 120 (1953).

---

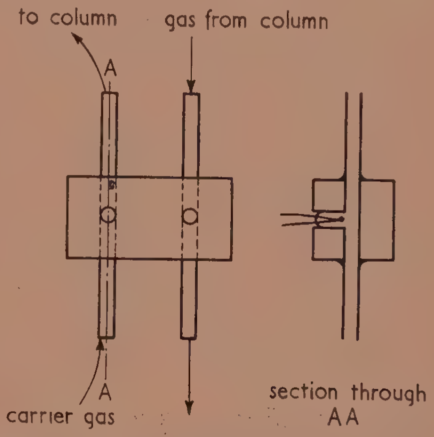
thermal conductivity gauge for use in gas-liquid partition chromatography

By D. Ambrose, B.Sc., Ph.D., and R. R. Collerson,
Chemical Research Laboratory, Teddington, Middlesex

[*Note first received* 23 *March, and in final form* 27 *April,* 1955]

everal papers have appeared recently(1,2,3) on gas-liquid artition chromatography, a technique in which a substance o be separated into its components is passed as a vapour nixed with a carrier gas (usually nitrogen or hydrogen), hrough a chromatographic column containing a non-volatile olvent absorbed on an inert support such as kieselguhr. eparation of the components during the passage through the olumn occurs when there are differences in their solubilities nd the success of the method, in particular with hydrocarbons here chemical detection is difficult, depends upon the use f a sensitive detector for the material eluted. One such etector is the thermal conductivity gauge consisting usually f two fine wires stretched in two tubes and connected in the djacent arms of a Wheatstone bridge circuit. A change in the thermal conductivity of the gas around the wires caused by a change in its composition affects their rate of heat loss and alters the position of balance of the bridge. The wire used in these gauges is very fine and their assembly not easy.

We have found that thermistors can be used in an easily assembled gauge to give satisfactory results. The body of the gauge was made from a rectangular copper block 2 × 1 × 1 in. in which holes were bored transversely to form two T's. The horizontal limbs of the T's received the connecting tubes, made of ¼ in. bore copper tubing, and the vertical limbs the two thermistors. The thermistors used are the directly-heated type A 2321, of nominal resistance 2000 Ω supplied by Standard Telephones and Cables Ltd., in which the sensitive bead hangs in a gas-filled tube; each tube was cut and cemented in the block as shown in the diagram so that the bead is exposed to the gas under analysis. The other two arms of the Wheatstone bridge consist of 390 Ω wire-wound resistors, current is supplied by a 2 V accumulator, and the opposite corners of the bridge are connected to a Honeywell Brown recording potentiometer of span 3 mV through a suitable zero adjusting network to bring the reading on scale. The two arms of the gauge are used differentially, the inlet gas passing through one arm before entering the column and the exit gas carrying the eluted material through the other as described by Bradford, Harvey and Chalkley.(3) After an initial stabilizing period the zero remains fairly constant and any drift can easily be distinguished from experimental changes.



Cross-section of copper block for thermal conductivity gauge

We have found the sensitivity of the instrument is comparable with the figures given by Ray(2) for a wire gauge, e.g. 0·01 ml. ethylene in a 20 ml. sample of gas gave a peak height of 1 mm. The characteristics of thermistors suggest that this gauge could be made more sensitive than a wire one but we have not so far tried to do so and recommend it chiefly for its small size and ease of assembly.

The work described above has been carried out as part of the research programme of the Chemical Research Laboratory and this note is published by permission of the Director of the Laboratory.

REFERENCES

(1) James, A. T., and Martin, A. J. P. *Biochem. J.*, **50**, p. 679 (1952).

(2) Ray, N. H. *J. Appl. Chem.*, **4**, pp. 21, 82 (1954).

(3) Bradford, B. W., Harvey, D., and Chalkley, D. E. *J. Inst. Petrol*, **41**, p. 80 (1955).

Correspondence

A laboratory gas-flow control device

The device described by R. A. Hall in the March issue of this *Journal* has been used in the gas industry for many years. It was developed by A. Edwards and is commonly called the Edwards' bottle. A description appeared in *Modern Gas Works Chemistry* by G. Weyman (London: Benn Bros. Ltd., 1922) while the mathematical derivation of the formulae and the best shape of the bottle were described by S. Pexton and W. K. Hutchison in the *Journal of the Society of Chemical Industry*, Vol. 48, page 242 (1929).

43 Harrow View Road, W. J. GOODERHAM
Ealing, London, W.5.

I must plead guilty to "re-discovering" the Edwards' bottle, with slight modifications due to the fact that my version was designed to deliver gas for reaction purposes, while the original was made for gas sampling at a constant rate. It is, of course, difficult to make quite certain that apparatus has not already been described somewhere in print; this particular device deserves, perhaps, to be more widely known.

The calculations in the paper quoted by W. Gooderham refer to a special design of gas sampler, and describe the "best shape" of the sampling bulb, not of the regulating device itself, which in fact, in this case, is acting as a liquid flow regulator. It is of course obvious, without calculation, that the gas flow will be the more constant, the smaller the ratio of the surface area of the inner tube to that of the reservoir.

Imperial Chemical Industries Ltd., R. A. HALL
Nobel Division, Stevenston,
Ayrshire.

A bent crystal X-ray spectrometer with roller bearing rotation mechanism

A vacuum spectrograph has been constructed and successfully employed to study emission spectra in the region of soft X-rays.(1) The spectrometer is of the reflexion type, its focal principle being Johann's(2) approximation to the ideal instrument first proposed by Dumond.(3) The spectrometer is designed for use with a fixed radiation source, the diffracting crystal and photographic detector rotating about a common axis. The detector is a plane photographic plate which is perpendicular to the incident radiation at the point where it meets the focal circle. The usual crystals may be employed in the spectrometer. With a muscovite (mica) crystal the instrument covers a first-order wavelength range of about 5–19 kX-units, the inverse plate dispersion being about 37 X-units/mm at 15 kX-units.

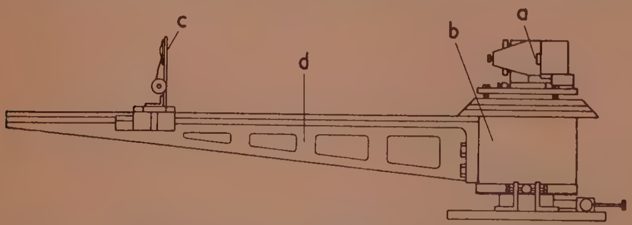


Fig. 1. Simplified front elevation of bent crystal X-ray spectrometer

An inspection of Fig. 1 will show that the spectrometer is independent of its associated apparatus and can be easily removed from its vacuum case for all fine adjustments. Tv straight edges at right-angles on the floor of the vacuum ca ensure that the spectrometer base plate may be correct relocated. The optically self-consistent nature of the desi facilitated placing the controls in accessible positions. Tl bent crystal in its holder *a* is placed directly over the rotatic mechanism *b*, the detecting plate being carried in a holder which slides on a rotating arm *d*.

The crystal is bent to a radius of 50 cm by being clamp between two (concave and convex) stainless steel bloc which were cylindrically profiled by the method of Dumon Lind and Cohen.(4) A channel cut in the convex blo allows the radiation to fall on the 1 cm square crystal apertu The latter may be limited by a knife-edge screen, while mea are provided for positioning the block assembly on a tab which may be adjusted at right angles to the rotation axis.

The detector arm is a steel fabricated T-sectioned cantilev bolted to the outer sleeve of the rotation mechanism. T surface and one edge of the arm determine the orientation the plate holder which bears upon them. A linear sca engraved on the other edge indicates the distance from t crystal rotation axis to the photographic plate.

The plate holder is easily loaded in a darkened room, simple spring device constraining the emulsion side of t plate to be always parallel to the rotation axis.

In the present instrument the crystal and detector m rotate, independently, about a common axis. Since cont of this rotation external to the vacuum is not required, t rotation mechanism involves no air-tight seal through t vacuum case. The use of precision taper roller beari (SKF 30302; 30210 by The Skefko Ball Bearing Co. Ltd.) h avoided the alternative and difficult task of producing double-cone bearing having a unique axis of rotation.

The details of the bearing assembly may be followed in t sectional view of Fig. 2. The base plate *A* supports a ri steel cylinder *B* to which is attached a brass disk *C*. A deg

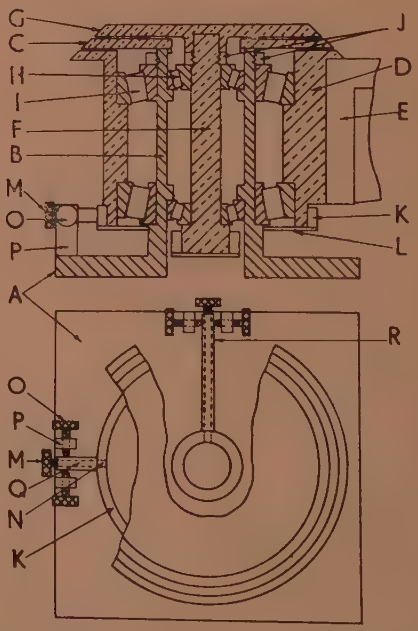


Fig. 2. Simplified sectional view of bearing assembly

ernier engraved on the bevelled edge of the latter allows the ngular settings of both the detector arm and crystal platform be determined. The outer rotating brass sleeve *D*, on hich is mounted the arm *E*, has an engraved degree scale n its bevelled edge. The inner rotating brass shaft *F* carries e crystal mounting platform *G*, the bevelled edge of which as an engraved degree scale. The figure shows how the ur sets of SKF bearings (*H* and *I*) are constrained by lock ngs *J*. Both the detector arm and crystal platform may be otated to any angular setting and locked in position with e controls indicated. For the arm, the outer sleeve carries slip ring *K* riding on the supporting disk *L*. When the and screw *M* is turned, it forces a brake pad *N* against the eeve, causing the slip ring to grip it firmly. Fine control nd locking of the arm is then possible with the two hand rews *O* (carried by supports *P* fixed to the base plate) orking against the control post *Q*. The angular setting of e crystal platform is effected in a similar manner with the cking control *R*.

Since only cylindrical boring and turning are involved, e design permits ready machining of the components of the otation mechanism to the close tolerances required. The earings were lubricated with a film of vacuum grease and ghtly pre-loaded in assembly. The spectrometer has been in ontinual use for some two years and the rotation mechanism as given complete satisfaction.*

The spectrometer was constructed in the workshop of e Canterbury College Industrial Development Department nd the author is indebted to Mr. R. J. W. Lindsay for his ssistance with the details of the rotation mechanism. The ork was made possible by the award of a National esearch Scholarship (Department of Scientific and Industrial esearch).

hysics Department,
anterbury University College,
hristchurch, New Zealand.

H. R. Moore

REFERENCES

) Moore, H. R., and Chalklin, F. C. *Proc. Phys. Soc.* [*London*]. To be published.
) Johann, H. H. *Z. Phys.*, **69**, p. 185 (1931).
) Dumond, J. W. M., and Kirkpatrick, H. A. *Rev. Sci. Instrum.*, **1**, p. 88 (1930).
) Dumond, J. W. M., Lind, D. A., and Cohen, E. R. *Rev. Sci. Instrum.*, **18**, p. 617 (1947).

* Upon request the author will supply detailed mechanical awings of the spectrometer.

Modification of an apparatus for preparing small sodium chloride crystals

e purpose of this note is to describe some modifications an apparatus discussed in a previous issue of this *Journal*.† e changes in design have been made in part as a result of ggestions from other users of the apparatus and in part a desire to prepare sodium chloride particles containing diochlorine. The original apparatus was hardly suitable r the latter purpose on account of the difficulty of deconmination. The essential features of the revised model are own in the sectional drawings of Figs. 1 and 2. In addition being more accessible for maintenance, this model gives improved standard of performance.

The principle of the apparatus is the same as for the previous model; the sodium chloride vapour is swept from the surface of molten sodium chloride (contained in a small platinum crucible) by means of diluent gas (e.g. nitrogen). The crucible for the present model has a volume of about 8 cm^3, and is gold-welded to a platinum apron (as suggested by Dr. G. C. Benson). The apron is sealed between the glass dome and transite support with thin asbestos rings.

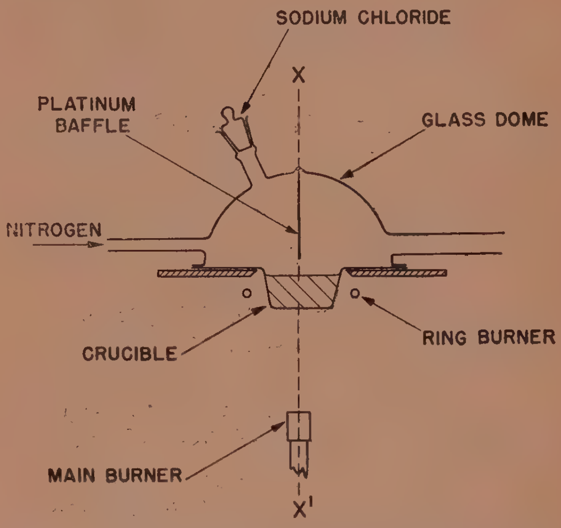


Fig. 1. Sectional view of apparatus for preparing small sodium chloride crystals

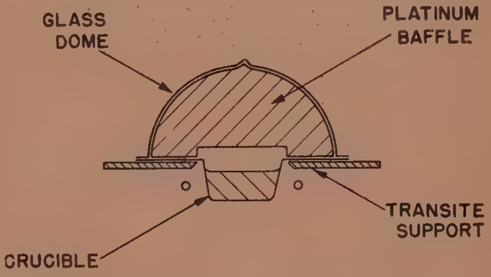


Fig. 2. Section through *XX′* of Fig. 1 showing baffle design

In order to prevent damage to the crucible by expansion of the sodium chloride upon melting, the crucible is heated initially with a gas-oxygen flame from a ring burner directed at the top of the crucible near the surface of the sodium chloride. Once the sodium chloride is molten, the crucible is heated with a gas-air flame directed at the bottom. Fortuitously in the previous model the heating element was wound around the upper part of the crucible. The significance of this was not realized until later, after several crucibles had been damaged in assemblies with heaters wound in a lower position.

Under similar conditions of operation, i.e. baffle dimension, flow rate of diluent gas and temperature of the crucible, the particle size and yield of small sodium chloride crystals are essentially the same as described previously.

Division of Pure Chemistry,
National Research Laboratories,
Ottawa, Canada.

F. W. Thompson
G. S. Rose
J. A. Morrison

---

† Young, D. M., and Morrison, J. A. *J. Sci. Instrum.*, **31**, 90 (1954).

New books

Optical glass working. By F. Twyman, F.R.S. (London: Hilger and Watts Ltd., 1955.) Pp. v + 275. Price 24*s.*

This is an abridged version of the author's *Prism and lens making* of which a considerably enlarged second edition appeared in 1952. As the name suggests, the book consists of that half of the latter which is directly concerned with the techniques and tests commonly used in the manufacture of optical components, and the book is intended as a handbook for the bench worker.

Nothing has been included which did not appear in the earlier publication and the task of the reviewer would therefore seem to be to comment on the choice and rearrangement of material and on the overall effect. The selection has on the whole been made wisely. Those topics which bear directly on the subject but have been expunged are not essential for those for whom the book is intended, and generally require prior physical knowledge. It is, perhaps, to be regretted that the original account of the nature of grinding and polishing is not reproduced even in condensed form. This might have been more valuable and in keeping with the spirit of the book than, say, the chapter on large object glasses and mirrors which few opticians meet at first hand. Non-spherical surfaces receive little attention and no account whatever is given of aspheric figuring which, although excusable, is perhaps short-sighted. The valuable glossary of terms, which was a very attractive feature of the 1952 volume, is included.

The printing and production are up to the usual high standard of clarity and serviceability of Hilger publications, and the book will undoubtedly appeal to optical workers. The optical researcher would still, however, be well advised to have at hand the larger parent volume. H. D. Keith

Transistor audio amplifiers. By Richard F. Shea. (New York: John Wiley and Sons, Inc.; London: Chapman and Hall Ltd., 1955.) Pp. xiii + 219. Price 52*s.*

Transistors have, virtually, only recently become available commercially though much has been written in the technical journals about them since transistor action was first discovered. The art of using these devices is so novel to most people that a book such as this for the practical engineer will be of great value.

The author has done his job with thoroughness, describing the three main ways of connecting transistors, their characteristics in the several connexions, how to design audio amplifier circuits and giving several practical amplifier designs. Whilst a good many pages are taken in reproducing characteristics of several American manufacturers' products, which may, of course, become dated, these do emphasize the general nature of the characteristics of these devices. It will be a little puzzling to the reader that the author's explanatory diagrams and those relating to the manufacturers' products have the axes of the graphs transposed so that the characteristics appear quite different at first sight.

Presentation of the whole matter in the book—text, diagrams, binding and typography—is extremely pleasing and does much towards real clarity of understanding and appearance. A. J. Maddock

A bibliographical survey of instrument parts, No. 1. Flexure devices, pivots, movements, suspensions. By P. J. Geary, B.Sc.Eng. (London: British Scientific Instrument Research Association, 1954.) Pp. 44. Price 10*s.* 6*d.*

This booklet is the first of a B.S.I.R.A. series of surveys of the literature on functional parts in instruments. These
surveys are intended to be as complete as reasonably possi
back to 1900 and, to judge by this first sample, they are go
to be valuable. In the present instance, there are
references, and abstracts are given of the principal twen
eight. The field covers flexure pivots, parallel movemen
twin strip mechanisms, buckling strip devices, rolling s
pensions and the sine spring—those movements (except
the torsion balance, which will be covered in another book
where "sliding and rolling are entirely done away with, a
sufficient freedom of motion is secured by the pliability
certain solid parts," and where "the motion of the piece
then affected by the elastic force of the suspension apparat
but this force is much more regular in its action than fricti
and its effects can be accurately taken account of." Th
quotations, which come from Clerk Maxwell's article in
Kensington Museum Handbook, show that the spr
suspension is just as classical as kinematic design; and t
might have been fittingly included among the introduct
quotations to the booklet. I offer them to the author
gratitude for two references which I had been trying to
for some months, and for which I should still be looking
for the timely appearance of this useful booklet.

R. V. Jone

Laboratory instrumentation in psychology. By Wm.
Grings. (Palo Alto, California: The National Pr
1954.) Pp. vi + 282. Price $4.75; 32*s.*

This book is presented as the outline of a one-session cou
on instrumentation for post-graduate students contemplat
research in psychology.

One glance at the contents leaves the reviewer full
sympathy for such students, whose requirements appear
range from a simple mercury manometer to elaborate elect
encephalograph and plethysmograph circuits, with sc
hundreds of instruments of extraordinary variety in betwe
The treatment of the subjects, which cover behaviour reco
ing, timing and counting, audition, vision and other sen
human learning and perception, and bioelectricity, is inevita
very superficial, though in parts quite lucid. Most of
instruments, mainly commercial, are described with
reference to their application in clinical practice. In
introduction, it is somewhat naïvely stated that several we
of preliminary teaching of elementary electricity, electro
and mechanics are required. To most teachers this "sev
weeks" would seem to be a massive understatement. As
indication of the enormous range of possibilities of phys
instrumentation in psychology and associated physiology
book has possible merit, but it is unlikely to find much
as a textbook in this country. J. E. Robert

Silver plating. (London: Johnson, Matthey and Co. L
Pp. 35.

This publication is not intended to be an exhaustive trea
on the electrodeposition of silver, but deals in a pract
manner with the various operations involved in silver plat
indicating suitable methods for most requirements and gi
warnings of possible difficulties.

The operation of silver plating may be sub-divided
three main sections (preparation, plating and finishing)
these are considered in the booklet under the appropr
headings. A further section deals with plating troubles,
useful appendices are included.

The booklet, the reference number of which is 185
obtainable from the company free on request.

New instruments, materials and tools

e Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved oducts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

C. differential current meter. Electrical Instrument Co. (Hillington) Ltd., Boswell Square, Hillington, Glasgow, S.W.2.

is instrument has been designed to measure differences in magnitude of two a.c. currents. The range of the instru- nt is usually only a fraction of the current passing through two circuits. For example, the scale of a meter for two rents of the order of 5 mA each may be 100–0–100 μA, h divisions equivalent to 5 μA, or a difference of 1 part 1000 in the two currents. Similar proportions apply to truments of other ranges. The instrument will not be naged if only one of the currents is switched on, even if maximum value, provided the range of the instrument is 0 of the load current or more. In the example quoted ove, these conditions are fulfilled. The meter is independent potential difference between the two circuits, provided this es not exceed 250 V. Currents of different frequency may compared provided the frequency ratio is not more than 1. This applies to all frequencies between 50 and 0 c/s. Currents of higher frequency may be compared if the same frequency up to 5 kc/s. Meters can be con- ucted not only to compare two approximately equal rents, but also to compare currents in such a way that the ll reading is equivalent to any desired ratio between the o currents.

bilized power supply unit. Edison Swan Electric Co. Ltd., 155 Charing Cross Road, London, W.C.2.

e stabilized power unit type R.1184 is designed to provide supply suitable for the operation of photo-multipliers, rticularly the Ediswan–Mazda types 27.M1, 27.M2 and M3. A continuous range of output voltage from 300 to 0 V is available. The output circuit is isolated from earth, d either the positive or the negative side may be earthed. e output control knob is calibrated in volts, and is accurate about 5%. The maximum current available at all voltages mA with less than 0·01% r.m.s. ripple. A change of 10% the mains supply voltage is claimed to produce less than % change of output voltage for outputs between 600 and 0 V. For outputs between 300 and 600 V the change is out 0·35%. The effective output resistance is given as proximately 1500 Ω. The short-term drift, after an initial rming-up period, is less than 0·25%; the long-term drift, er an initial ageing, is less than 1% per thousand hours.

ctric "Bunsen." Electrothermal Engineering Ltd., 270 Neville Road, London, E.7.

electric "Bunsen" is available which has a heating element ich, it is claimed, is resistant to rapid changes in tempera- e. The radiation from the heater is directed upwards only d the temperature is adjustable. The heater can be used such purposes as heating test tubes, crucibles, small flasks d beakers independent of their shape. By using it inverted, an provide the heat source for evaporation processes. The paratus is made of corrosion-resistant metal. It consists a specially formed replaceable heating element mounted in top of a vertical tube, which forms the supporting case. is tube is provided with air circulation holes in the lower t and a concentric gap left between the heating element d the casing prevents any undue temperature rise. The ter is provided with rubber feet. It can be comfortably d in the hand while operating. The conical working cavity of the heating element, which consists of a nickel/chrome wire embedded in a refractory aluminium oxide casing, is formed in such a way that the radiant heat is concentrated and directed to the centre and top of the cavity, i.e. the position the lower part of a test tube will occupy when the heater is in use. A cowl provided at the top of the unit is designed to deflect heat radiation away from the hand.

Electric "Bunsen"

The heater has the following specification:

power loading	300 W
standard voltages	110/130 V, 200/230 V or 230/250 V
element temperature	800–1000° C
overall height	6¾ in.
cowl diameter	3¾ in.
base diameter	4¾ in.

A microelectric "Bunsen" is also available.

Miniature potentiometer. Technology Instrument Corporation, 531 Main Street, Acton, Mass., U.S.A.

The ten-turn potentiometer, type L10S, in spite of its small size (1⅜ in. long × ¾ in. diameter), is claimed to have the excellent linearity of 0·05% on standard models or 0·025% on special models. The instrument has a mechanical rotation of 3660° and an electrical rotation of 3600°. Fixed taps can be provided located to within 1° of the correct position. The use of ball bearings is responsible for the low operating torque, which the makers state to be 0·75 oz in. when starting and 0·60 oz in. when running. The device is available in resistances from 1 to 100 kΩ. On standard models the resistance is guaranteed to be within 5% of the nominal value; special models can be provided with a tolerance of 1·0%.

Notes and comments

The Instrument Directory

We have received a copy of the first annual number of *The Instrument Directory* which is issued without extra charge to subscribers to the monthly periodical *Instrument Practice*. This 208-page book is divided into the following six sections: List of consultants, engineers and installers of instrumentation schemes; List of firms manufacturing single or small batches of instruments to a client's order; Classified list of instruments and components arranged alphabetically with suppliers' names; Alphabetical list of instrument and component manufacturers with overseas agents; List of specifications directly bearing on instrument matters issued by official bodies; Trade names. The difficulties in compiling such a work are very great and the publishers are to be congratulated on the success of their efforts. As the author of the foreword remarks "An instrument, in these times, can consist of a simple magnifier or a complex electronic computer occupying a building to itself, and between the two examples can lie an infinite number of different devices. The problem is to establish the limits. There is a further complication. The rapid progress of electronic applications in the instrument field has meant the use of a multitude of components such as valves, capacitors, resistors, transformers, etc., whose manufacturers must definitely find a place in the *Directory*."

The field covered is measuring and control under 1500 classified headings. The entries have been made from information supplied by the firms and anyone who has worked from such data will realize that some of the material is not very helpful. No doubt the many users of this *Directory* will have comments and suggestions for improvement and these will be welcomed by the publishers.

Post-graduate courses in instrument technology

The National College of Horology and Instrument Technology, in conjunction with the Instrument Engineering Department of Northampton Polytechnic, conducts single-session (October–July), full-time courses in instrument technology for students holding either a university degree in science or engineering, or a Higher National Certificate (or Diploma) in engineering, or an equivalent qualification. The aim of the course is to provide specialized or supplementary training in the field of instrument technology.

The next session commences in October 1955. Application forms and prospectuses may be obtained from the Secretary, National College of Horology and Instrument Technology, Northampton Polytechnic, St. John Street, London, E.C.1.

British Nuclear Energy Conference

In the light of recent rapid developments in the technology of nuclear energy, and the increasing demand for a common ground between scientists and engineers where these developments can be discussed, an organization has been formed by the Institutions of Civil, Mechanical, Electrical and Chemical Engineers, and The Institute of Physics, to satisfy this need. This will be known as the British Nuclear Energy Confere the affairs of which will be managed by a Board consist of three representatives from each of these societies. Chairman is Sir Christopher Hinton, and Sir John Cockc is one of its distinguished members. The Secretary is Alexander McDonald (Secretary of The Institution of C Engineers, Great George Street, London, S.W.1).

The five institutions will arrange for the presentation papers dealing with nuclear energy subjects, and all th members will be able to attend and take part in the disc sions. The Conference will publish a Journal about f times a year containing records of the papers, discussio symposia and conferences conducted by the Board. T Journal will be offered for sale.

The Board proposes to hold its inaugural meeting in autumn at which a symposium of lectures will be delive on the technology of nuclear energy and its applicatio The Board also proposes to promote national and int national conferences from time to time, and to arrange British participation in international meetings.

The expenses of the Conference will be met by the insti tions, although it should be self-supporting once it is fu established.

Journal of The Institution of Telecommunication Engineers

We have received the first issue of a new quarterly publis in New Delhi by The Institution of Telecommunicat Engineers which was established in India in connexion w the telegraph centenary celebrations in 1953. The is before us has 58 pages of text measuring $7\frac{1}{4} \times 9\frac{3}{4}$ in. an nicely printed and produced. Only twenty of these pa are devoted to scientific papers, the others recording inaugural exercises of the Institution and other dome news and reports. The titles of the three papers are: L fault location by pulse technique; On radio measurement Jabalpur during the Solar eclipse of 30th June, 1954; Po density diagrams of short-wave aerial arrays.

The annual subscription to the Journal is 15 Rs. and address of the new Institution, to which subscriptions sho be sent, is P.O. Box 481, New Delhi, India.

British Journal of Applied Physics

Contents of the August issue

SPECIAL ARTICLE

Mass transfer theories of fuel bed combustion. By R. S. Silver and R. W. Ma

ORIGINAL CONTRIBUTIONS

Changes in the structure of oxide cathodes at high temperatures. By H Rooksby.

Identification of materials by electron diffraction in the electron microscope H. I. Matthews and H. Wilman.

The flexural vibrations of an end-loaded vertical strip. By R. F. S. Hearmo E. H. Adams.

Phenomenological approach to "current" noise. By D. A. Bell.

Electron liberation by low energy ions at metal surfaces and in gases. By H.

The square wave response method of analysing process control systems. L. Mandel.

NOTES AND NEWS

New books

Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principles construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Square London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation* *contributions*. (Price 2*s*. 6*d*. including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon applicatio from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, London E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within 6 days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of addres or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £4 per volume ($11.50 U.S.A.), including index (post paid) payable i advance. Single parts, so far as available, may be purchased at 8*s*. each ($1.15 U.S.A.), post paid, cash with order. Orders should be sent to The Institute o Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

A short duration, double-flash system for simultaneous or delayed operation

By N. Dombrowski, Ph.D., and R. P. Fraser, O.B.E., Imperial College of Science and Technology, London, S.W.7, and G. T. Peck, Ernest Turner Electrical Instruments Ltd., High Wycombe, Bucks

[*Paper first received* 27 *September*, 1954, *and in final form* 24 *January*, 1955]

An account is given of the development of an apparatus employing two separate flash discharge tubes operated either simultaneously or consecutively with a means to vary the interval from 0·01 to 10 ms. The two sources of an energy of 5 J are designed for a flash duration of 6 μs at 10% of peak light. An example is given of the application of the apparatus to the study of the mechanics of spray nozzles.

Many non-recurring rapid events can be conveniently studied y taking a relatively large number of photographs to investigate the history of the occurrence by means of high-speed inematography. Some rapid events, as, for example, those ssuing in fluid flow, are continuous in character and even wo photographs taken in rapid succession on the same mulsion can provide a history of the event. In such cirumstances the use of the high-speed cinematograph camera s unnecessary. An alternative system using two synhronized flash discharge light sources may be used in conjunction with a conventional camera, to obtain two exposures on the same negative separated by a short but known interval of time.

BASIS OF THE DESIGN

To effectively analyse movement disclosed by double exposures on the same negative, it is necessary to know the nterval between the two exposures with considerable accuracy, and to be able to repeat this interval consistently and reliably.

Because many phenomena to be investigated occur very rapidly, it is essential to use the shortest practicable exposure. At the same time, adequate illumination is necessary to allow arge image-object ratios and permit the use of small lens apertures to obtain the depth of field required. In addition t is desirable to have a light source of the smallest possible dimensions to enable efficient utilization of the light to be obtained in a reflector system.

In some respects these requirements are conflicting and suggest the use of flash discharge tubes operating at a comparatively high voltage. Under high voltage conditions, however, conventional tubes with external or internal trigger electrodes are known to become unstable and exhibit erratic delays of several microseconds between the application of the riggering pulse and the breakdown of the gas column.

These limitations and control difficulties were overcome by the use of Siemens type SF/E1 small bore high pressure xenon tubes operated in series with individual heavy current hydrogen thyratrons. A protecting bulb surrounding the quartz button of the light source is silvered internally and positioned to act as a reflector, for increasing the utilization efficiency. By this means it is possible to retain the high photographic efficiency of a discharge in xenon(1) with the precision of the hydrogen thyratron switch.(2) The development and measurement of such a system has been fully described elsewhere(3) and will not, therefore, be referred to n detail here.

OPERATION OF THE SYSTEM

The two light sources may be flashed together or independently, or one lamp may be flashed subsequent to the other. When the lamps are operated to give simultaneous single flashes the high voltage power supplies and storage condensers are connected in series at 12 kV and controlled by one hydrogen thyratron switch. When the two lamps are flashed independently they are operated at 6 kV, giving a flash energy of 5 J in each lamp. The flash characteristic determined photographically under these conditions is shown in Fig. 1.

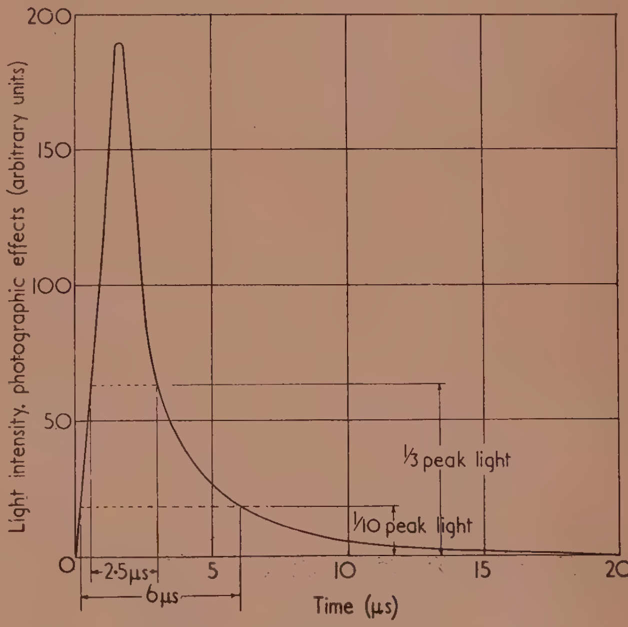


Fig. 1. Variation of light intensity (photographic effects) with time

If the criterion of flash duration is accepted as that when the light has fallen to one-tenth of its peak value,(3) then the effective time of exposure is observed in the curve to be 6 μs. This level of intensity is arbitrary and can be varied in practice by altering the lens aperture, sensitivity and contrast of the emulsion. Thus Fig. 1 shows that the effective time of exposure is reduced to 2·5 μs when the light intensity is at one-third of its peak value. The change in exposure time is thus obtained by utilizing only a portion of the total available light. This variation can be seen in Fig. 2, which is derived from the characteristic intensity-time curve in Fig. 1 by integrating the curve at a series of intensity levels. It shows that if 64% of the total light output can be used, then the time of exposure may be reduced from 20 to 6 μs. If the amount of light utilized can be reduced to half this value, then an exposure time of 2·5 μs can be obtained.

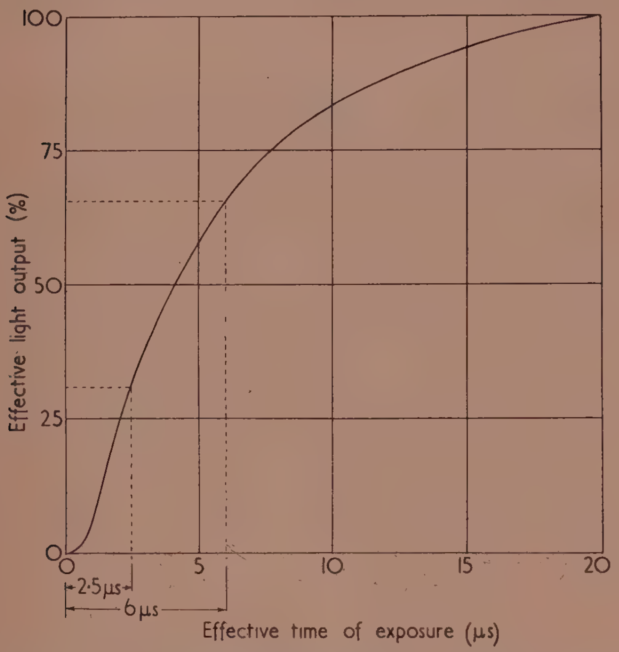


Fig. 2. Variation of effective time of exposure with effective light output

By the addition of further condenser capacity the flash energy in each lamp can be increased at 20 J. Under these conditions the flash duration at 10% peak is 15 μs.

When the lamps are flashed subsequent to each other an electronic delay circuit is introduced calibrated from 0·01 ms to 10 ms.

ELECTRICAL CONTROL CIRCUIT

The basic circuit is shown in Fig. 3. In switch positions 1 and 2 conventional half-wave selenium rectifiers charge alternate energy storage condensers to 6 kV. The individual flash discharge lamps in series with separate hydrogen thyratron switches are connected across each condenser as shown in Fig. 4(*a*). In positions 3 and 4 of the switch, the rectifiers and alternate energy storage condensers are rearranged in series and 12 kV is applied to the two lamps in series with one hydrogen thyratron switch, as shown in Fig. 4(*b*). A resistance of high value is connected across each lamp to maintain a constant potential at the anodes of the hydrogen thyratrons.

Identical and separate triggering circuits (channels *A* and *B*) are provided for each flash discharge lamp to enable each to be operated independently. These triggering circuits are shown in block form in Fig. 3 and permit initiation of either flash by electrical contacts or pulses applied to a single shot multivibrator (V_1, V_4), the output pulse of which is amplified, shaped (V_2, V_5) and applied to the grid of a xenon-filled thyratron (V_3, V_6). When this valve conducts, the l
impedance cathode circuit applies a positive pulse
approximately 350 V to the grid of the hydrogen thyratr
switch (V_{12}, V_{13}) to establish current between the grid a

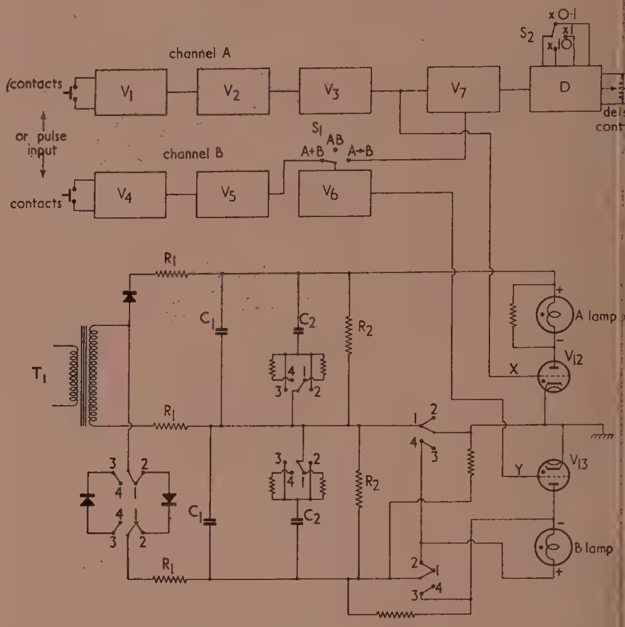


Fig. 3. Schematic diagram of power pack and delay circuit

Switch positions
1 5J } parallel
2 20J
3 20J } series
4 5J

C_1 = low power discharge condens
C_2 = high power discharge conden
S_1 = lamp selector switch
S_2 = range switch
T_1 = extra high-tension transformer
R_1 = charge resistance
R_2 = bleed resistance
D = delay circuit charging dio
(included to facilitate repeti
triggering when calibrating)

cathode, and so trigger this valve and allow the ener
storage condensers to discharge through the respective fla
discharge lamp. The grid pulse is of short duration with
rise time of less than 1 μs to reduce ionization time a
ensure consistent operation and, in conjunction with t
very short de-ionization time characteristic of hydrog

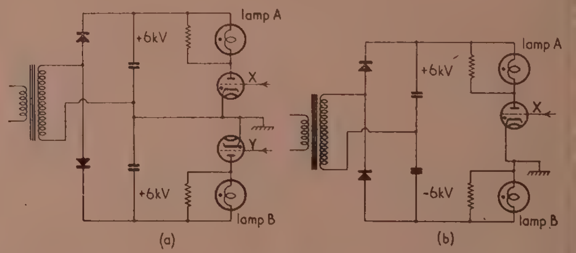


Fig. 4. Circuits for (*a*) parallel and (*b*) series operation

prevent the discharge from becoming oscillatory w
consequent lengthening of the flash duration.

Complete separation and some screening of the triggeri
circuit is necessary to avoid instability from the high pe
currents in the lamp discharge circuits, and electrotherm
means of varying the internal gas pressure of the hydrog
thyratrons enables the operating characteristics of individ
valves to be adjusted.

DELAY CIRCUIT

To enable the second lamp to be flashed subsequent to the irst, after a determined period, a calibrated time delay ircuit (V_7) is introduced between the two triggering circuits.

After several attempts, reliable and consistent operation vas obtained by the use of the Phantastron(4), a comparatively imple electronic circuit using a type 6SA7 pentagrid in onjunction with a cathode follower to produce variable time lelays free from short time jitter and stable over relatively ong periods. To simplify calibration, provision is made to operate the delay circuit repetitively, so that if a frequency of precisely 1000 c/s of suitable waveform and amplitude is pplied to the input, the two triggering pulses may be presented on an oscilloscope and the delay potentiometer ccurately calibrated at 1 ms. The delay is a linear function of the control voltage and the calibration of intermediate points presents no difficulty. A three-position multiplier witch in conjunction with the potentiometer permits adjustment of the delay time from 0·01 to 0·1, 0·1 to 1 and 1·0 to 10 ms respectively.

The calibration of the overall delay was finally checked by photographing with the two flashes a white line on a 15 cm liameter disk rotating at 14 000 rev/min for the two lower anges and 1400 rev/min for the highest. The time intervals vere then determined from the distances between the two mages.

The precision of the instrument is given by the 95% confidence limits about the regression line. These limits are ±0·0012, ±0·011, ±0·11 ms respectively from the lower to he higher ranges.

SOME APPLICATIONS TO THE STUDY OF SPRAY NOZZLES

A study of the manner of flow through the nozzle, the vay in which the liquid flows in the sheet, its subsequent lisintegration and the behaviour of the liquid drops through he atmosphere, has resulted in a greater understanding of he principles underlying the atomization of liquids. An pplication of the double-flash system to a study of the nanner in which liquid sheets disintegrate is illustrated. A uller account of this work has been published elsewhere.(5)

Fig. 5 is a photograph taken with the two light sources operating consecutively with an interval of 0·4 ms. It llustrates the history of a flat sheet of liquid issuing from a ingle-hole fan-spray nozzle. Upon leaving the orifice the iquid forms a thin sheet which becomes thinner as its area ncreases. Some small areas attenuate more rapidly than the emainder of the sheet and lead to holes forming in the heet. These holes increase in size as the liquid at their dges is drawn back to form thicker rims under the action of surface tension. This may be observed at point *A* where wo holes are seen at the first exposure. These increase in liameter rapidly at the rate of 590 cm/s, so that at the second xposure (point *B*) they are separated by only a thin thread. The corresponding increase in the thickness of the rims ounding the holes can be observed. By this process a etwork of threads of a wide range of diameters is formed eaving small sheets of liquid at the junctions of several oles. These threads break up into chains of drops, a few iving fairly uniform main and satellite drops, while the najority break up irregularly. Point *C* shows the transition rom a thread to a chain of drops. The holes in the sheet are reproduced as voids in the resultant clouds of drops. The sheets of liquid which are left at the junctions of a number of holes are drawn up into relatively large masses which disintegrate later into a cluster of heterogeneous drops. A method has recently been described(6) whereby the two exposures may be easily identified.

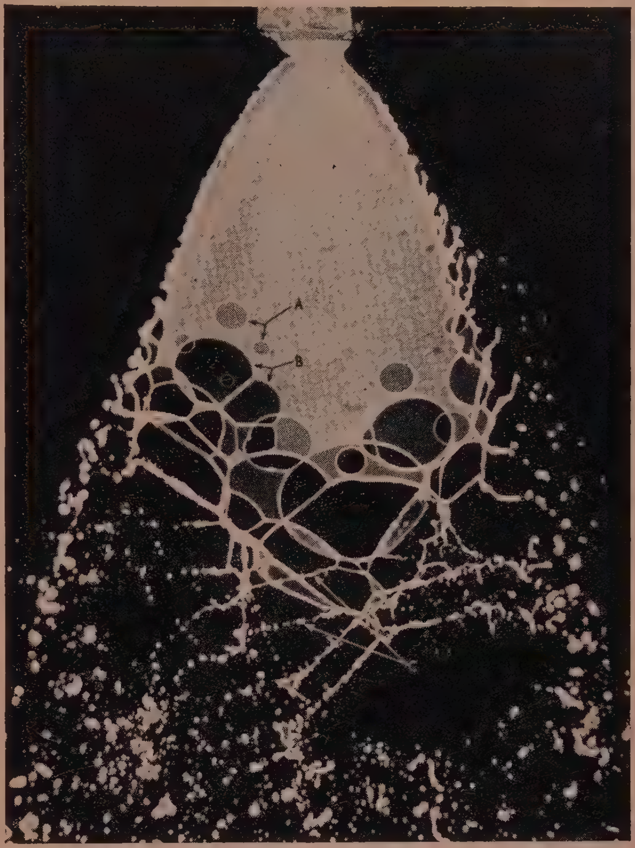


Fig. 5. Double-flash photograph of spray sheet (×1·98)

ACKNOWLEDGEMENTS

The apparatus described was developed by Ernest Turner Electrical Instruments, Ltd., and the special xenon light source by Siemens Electric Lamps and Supplies, Ltd. The research was carried out under a grant provided by the Agricultural Research Council.

REFERENCES

(1) ALDINGTON, J. N., and MEADOWCRAFT, A. J. *J. Instn Elect. Engrs*, **95**, p. 674 (1948).
(2) KNIGHT, H. DE B. *BTH Activ.*, **20**, p. 52 (1949).
(3) CHESTERMAN, W. D., GLEGG, D. R., PECK, G. T., and MEADOWCRAFT, A. J. *J. Instn Elect Engrs*, **98**, p. 620 (1951).
(4) CLOSE, R. N., and LEBENBAUM, M. T. *Electronics*, **24** (4), p. 100 (1948).
(5) DOMBROWSKI, N., and FRASER, R. P. *Phil. Trans. A*, **247**, p. 101 (1954).
(6) DOMBROWSKI, N. *Brit. J. Appl. Phys.*, **6**, p. 17 (1955).

A magslip isograph

By G. M. Parker, B.A.,* and R. W. Williams, Ph.D., A.Inst.P., The English Electric Company Ltd., Luton, Bed

[*Paper received* 27 *April*, 1955]

An isograph is described in which the terms of the polynomial equation to be solved are represented by alternating voltages of varying time phase obtained from magslip transmitters in association with resistance potentiometers. The application of this principle results in a compact machine capable of finding roots with good accuracy. The isograph may also be used for the evaluation of polynomials.

In recent years several analogue computers for the solution of polynomial algebraic equations (isographs) have been described in the literature. The working principle of one of the earliest isographs†—the representation of the terms of the polynomial by variation of the time phase of a.c. generator outputs—has attracted less attention subsequently than it deserved, and the present paper concerns an isograph based on this principle in which the application of modern analogue computing techniques has resulted in a compact instrument of useful accuracy. As constructed the isograph is capable of solving sixth-degree equations having real coefficients but the principle could be extended readily enough to deal with equations of a higher degree with complex coefficients.

BASIC PRINCIPLE

Consider an electrical machine provided with a three-phase stator winding having two poles per phase, and a single-phase rotor winding. If the stator winding is excited from a balanced three-phase supply of pulsatance ω, a rotating magnetic field is produced in the machine and the output of the rotor winding will be an alternating voltage of pulsatance ω. The time phase of this output will vary directly with the angular position α of the rotor: its amplitude e will be constant if that of the stator supply is constant. Assuming that $\alpha \ll \omega$, any rotary modulation effects may be neglected and the output can be represented as $e \sin(\omega t + \alpha)$.

Let us now examine the expression

$$a_6 r^6 \sin(\omega t + 3\theta) + a_5 r^5 \sin(\omega t + 2\theta) + \\ + \ldots + a_0 \sin(\omega t - 3\theta) \quad (1)$$

This is easily shown to be equivalent to

$$\sin \omega t . \mathscr{R}[P(z) \exp(-3i\theta)] + \cos \omega t . \mathscr{I}[P(z) \exp(-3i\theta)] \quad (2)$$

where $P(z)$ is the polynomial

$$a_6 z^6 + a_5 z^5 + \ldots + a_1 z + a_0$$

by writing z in the form $r \exp(i\theta)$. The basis of the isograph is the realization of the terms of expression (1) by means of machines of the type just described, whose rotors are geared together and turned through the angles 3θ, 2θ, ... -3θ respectively. Resistance potentiometers fed from the rotor outputs are used to effect multiplication by the coefficients a_6, a_5, ... a_0; similarly the powers of r are introduced by means of cascaded linear potentiometers, the rotation of the sliders of which is proportional to r.

Finally the seven voltages corresponding to the terms of expression (1) are summed, the resultant voltage being displayed on a suitable meter. Now if it is required to evaluate the roots of the equation $P(z) = 0$, r and θ are varied until the meter reads zero. When this is the case it is evident from expression (2) that the settings of r and θ then define a ro of the equation. If means are provided for measuring t time phase of the voltage which is applied to the meter, t instrument may be used to evaluate polynomials in additi to finding their roots. For a given value of the independe variable z, which is set into the isograph in polar form (r, the meter reading represents the modulus of expression (which is simply $|P(z)|$. Let the argument of $P(z)$ be ϕ. T phase angle β of the meter voltage is seen from expression (to be the argument of $P(z) \exp(-3i\theta)$, which is $\phi -$ 3 Hence ϕ is known, being $\beta + 3\phi$. The value of $P(z)$ is n determined in polar form.

GENERAL DESCRIPTION

The 2 in. magslip coincidence transmitter is a very co venient means of producing voltages of the form $e \sin(\omega t +$ as required in the isograph. Six such transmitters a assembled in a mechanical unit; they are arranged in thr pairs, geared together so that their rotors are turned throu angles of $\pm\theta$, $\pm 2\theta$ and $\pm 3\theta$ respectively. The magslip stat windings are excited from a balanced 50 V 50 c/s three-pha supply. Typical of the seven channels in the isograph is t one which forms the term $a_6 r^6 \sin(\omega t + 3\theta)$ and a schemat diagram of this channel is shown in Fig. 1. The magsl output, which is at a level of about 30 V r.m.s., is taken a precision resistance potentiometer R_1 *via* the reversi switch S. The coefficients a^6 is represented by the angu setting of the slider of R_1, the position of S being selected accord with the sign of the coefficient. The output of R_1

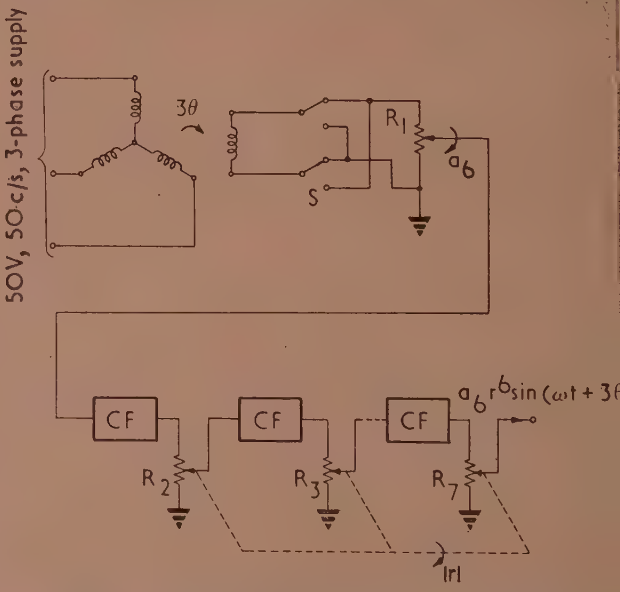


Fig. 1. Formation of the term $a_6 r^6 \sin(\omega t + 3\theta)$
CF, cathode follower

---

* Now at Canadian Westinghouse Co. Ltd., Hamilton, Ontario.

† Herr, D. L., and Graham, R. S. *Rev. Sci. Instrum.*, 9, p. 310 (1938).

hen applied to the cascade of multiplying potentiometers $R_2 - R_7$ whose sliders are coupled together and set for $|r|$, he modulus of the independent variable. Successive units of the cascade are isolated by means of cathode-follower buffer amplifiers. The output voltage of R_7 represents the final term $a_6 r^6 \sin(\omega t + 3\theta)$.

Since the term $a_3 r^3 \sin \omega t$ is of constant time phase, the voltage for the a_3 coefficient potentiometer is obtained from a transformer excited from one phase of the 50 c/s supply. It may also be remarked that the term $a_0 \sin(\omega t - 3\theta)$ does not involve multiplication by r, so that the output of the a_0 potentiometer, after passage through a cathode-follower buffer stage, is not subjected to any further processing. The seven voltages produced in the manner of Fig. 1 are summed in a feedback amplifier whose output is taken to the display meter of the isograph.

The principal components of the isograph (magslip unit, display panel, $|r|$ multiplier unit, cathode-follower stages, summing amplifier) will now be considered in more detail. Some attention will also be given to the power supplies, including the 50 c/s three-phase supply. The isograph itself occupies a standard rack 19 in. wide and 6 ft high; the three-phase supply is generated electronically and its components are housed in a similar rack of half the height.

PRINCIPAL COMPONENTS OF THE ISOGRAPH

Magslip unit. The magslip unit consists essentially of a stout baseplate on which are mounted the coincidence transmitters and a velodyne motor-generator unit (type 74) geared to them. The velodyne is used in a conventional rate servo circuit so that the transmitter rotors may be driven at a steady rate, the rotational speed being controlled by means of a knob on the display panel. A switch in the motor armature circuit enables the operator to de-energize the velodyne, thus permitting fine adjustment of θ by hand. The velodyne shaft carries a dial having a shaft value of 20° per revolution and graduated in $\frac{1}{5}$° divisions. One of the transmitters driven for θ is provided with a dial covering 360° in divisions of 20°. The arrangement of dials allows θ to be read off easily to 0·1°; the backlash over the whole gear train is of this order. The choice of transmitter rotor angles on the basis of $3\theta, 2\theta, \ldots - 3\theta$ rather than $6\theta, 5\theta, \ldots \theta$ was made to facilitate the mechanical design of the unit. It was also considered to have certain advantages in connexion with the display of the polynomial on a cathode-ray tube if this feature is ever required. There is the minor disadvantage that the expression $\phi = \beta + 3\theta$ must then be used for the determination of the argument of the polynomial.

Display panel. The seven coefficient potentiometers (Colvern type CLR7302, 100 kΩ, linear to within ±0·1% of maximum output) are located on the display panel, together with their associated reversing switches. They are provided with dials calibrated from 0 to 1 in divisions of 0·01 which permit the setting of the coefficient values to within 0·002. In addition the panel houses: the $|P(z)|$ display meter and its scale-changing switch; a meter and a coincidence transmitter used in a phase-finding circuit for the determination of β; an assembly of push-button switches and pre-set potentiometers which facilitate the initial adjustment of the isograph channels. Since these items are associated with the summing amplifier, they will be discussed with it.

$|r|$ *multiplier unit.* A total of twenty-one multiplying potentiometers is required for the formation of the powers of r. Seven triple-gang potentiometers, Colvern type CLR7316, the units of which are of 10 kΩ total resistance and are linear to within 0·1% of maximum output, are installed on a base plate similar to that used for the magslip unit, and geared together. They are driven from a hand control through a reduction gear of 10 : 1 ratio. The maximum value of $|r|$ is unity; the procedure followed in extending the operation of the isograph outside the range $0 < |r| < 1$ is explained below. An arrangement of coarse and fine dials enables the operator to read $|r|$ easily to within 0·001. The turn-to-turn spacing of the potentiometers is of this order, so that any further elaboration of the $|r|$ dials is not warranted.

Cathode-follower stages. It is of prime importance to avoid loading errors in the $|r|$ potentiometers and for this reason successive units in the multiplying cascades are separated by cathode-follower stages. The circuit diagram of the stage is shown in Fig. 2. Measurement of the transmission ratio of the stage as a function of the amplitude of the input signal showed that errors arising from the variation of this ratio were acceptably small. At the operating frequency (50 c/s) the phase shift introduced by the coupling condenser is not negligible. The overall phase shift in a cascade may be appreciable but it is readily compensated by adjustment of the mechanical phase of the coincidence transmitter rotor which feeds the cascade. This adjustment forms an essential part of the initial setting-up procedure. The overall attenuation introduced by the cathode-follower stages varies, of course, from cascade to cascade. The values of the resistors in the summing arms which accept the outputs of the cascades are chosen so that these outputs make their correct relative contributions to the total signal representing $|P(z)|$. Here again the fine adjustment of the summing arms is carried out as part of the setting-up procedure.

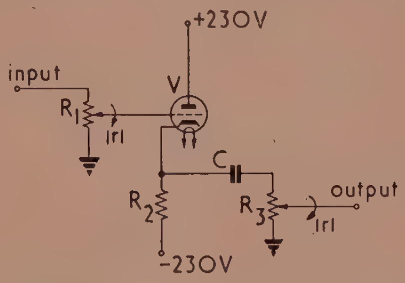


Fig. 2. Circuit diagram of cathode-follower buffer stage

R_1, R_3 = Colvern type CLR7316, 10 kΩ
R_2 = 27 kΩ
C = 4 μF
V = 6SN7GT

The total number of cathode follower stages required is twenty-two—twenty-one for the $|r|$ potentiometers and one for the output of the a_0 coefficient-setting potentiometer. This latter is of 100 kΩ total resistance and would otherwise be badly loaded by the 1 MΩ resistor of the summing arm which it feeds. The other summing arms are fed from $|r|$ potentiometers of 10 kΩ resistance and loading effects here are negligible. The cathode-follower stages are installed in one chassis; the use of double triodes reduces the number of valve envelopes required to eleven.

Summing amplifier. The function of the summing amplifier is to produce an output voltage proportional to the sum of the seven voltages representing the individual terms of expression (1). Fig. 3 is a schematic diagram of the summing arrangements. A network having seven resistance arms $R_1 \ldots R_7$ accepts the output voltages of the multiplying cascades: the star point of the network is connected to the amplifier input grid terminal. An eighth resistance arm is provided to feed the amplifier output negatively back to this point. For clarity, the push-button switching circuits used for comparison of each channel in turn with the datum channel (a_3) during the initial setting-up of the isographs are omitted from Fig. 3. The overall gain of the amplifier is controlled by means of a six-position, four-pole switch, pole b of which selects the fraction of the amplifier output which is fed back. Four of the switch positions are calibrated for the evaluation of polynomials: they give full-scale deflexion of the output meter corresponding to $|P(z)| \doteq 5$, 1, 0·2 and 0·05 respectively. The uncalibrated positions give the highest overall gain and are used for root location. In these positions, pole c of the switch interposes a filter circuit between the amplifier output and the meter. The filter removes most of the harmonics present in the output signal and permits a very much higher reading accuracy than would otherwise be achieved. With the filter in use, the accuracy of the machine is sensibly independent of the distortion introduced in the multiplying cascades and of the harmonic content of the three-phase supply. On the highest gain settings, large jumps in the output are observable due to the potentiometer steps in the cascades. Pole a of the switch applies shunting networks across the input grid to assist in the stabilization of the amplifier in the positions of heavy feedback. The output meter is a moving coil d.c. instrument having a full-scale deflexion of 1 mA, used in a bridge rectifier circuit. In the four calibrated switch positions, pole d provides current feedback through the rectifier bridge so that non-linear effects in the rectifiers are reduced.

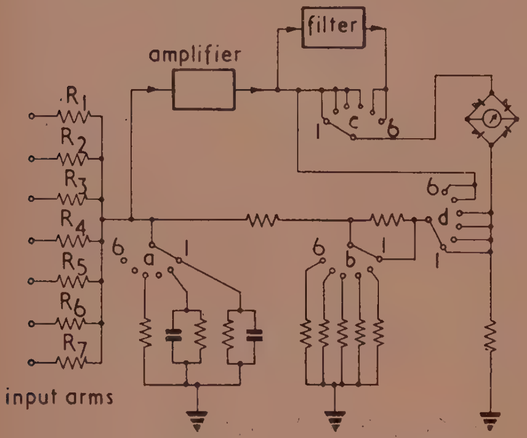


Fig. 3. Schematic diagram of summing circuit

The summing amplifier has three resistance-capacity coupled stages of conventional design, incorporating anti-sing networks to ensure stability under working conditions. The filter unit consists of a two-stage resistance-capacity coupled amplifier. A twin T-circuit tuned to 50 c/s and having an effective Q of about ten provides selective feedback from the anode of the first stage to the input grid.

The phase-finding circuit is shown in Fig. 4. The output of the summing amplifier is applied to a phase-sensitive rectifier, the polarizing voltage for its diodes V_1, V_2, being obtained from the rotor of a coincidence transmitter, fed from the three-phase, 50 c/s supply. The rectifier output is taken to a differential cathode-follower circuit (V_3, V_4), a d.c. meter having a full-scale deflexion of 1 mA being connected between the cathodes of V_3 and V_4. The meter is uncalibrated except for a reference mark at half scale. In operation the press switch S_1 is first used to earth the input to the rectifier and the potentiometer in the cathode circu of V_3, V_4 is adjusted until the meter pointer is brought to t reference mark. To measure the time phase of the summi amplifier output, S_1 is released and the rotor of the coinciden transmitter is turned until the pointer returns to the referen mark. To achieve high setting sensitivity, the press swit S_2 is operated so as to apply full signal to the grid of V_3. is clear that the transmitter rotor voltage is then in tin quadrature with the amplifier output signal and the rot position (read off to within 1° by means of a suitable dia is the measure of the angle β. The 180° ambiguity which possible in the phase readings is resolved by taking only tl null in which the pointer moves from left to right as the ma slip dial is turned clockwise.

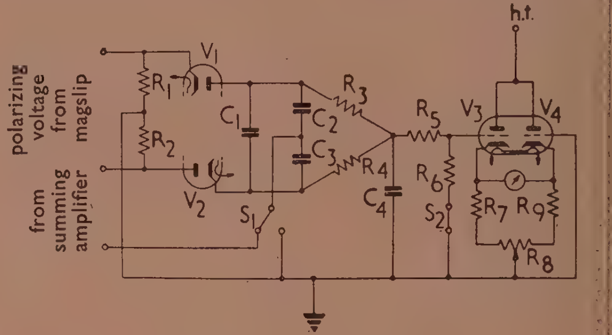


Fig. 4. Circuit diagram of phase-finding unit

R_1, R_2 = 10 kΩ
R_3, R_4 = 680 kΩ
R_5 = 180 kΩ
R_6 = 27 kΩ
R_7 = 680 Ω
R_8 = 500 Ω
R_9 = 820 Ω

C_1 = 2 μF
C_2, C_3 = 0·1 μF
C_4 = 0·5 μF
V_1, V_2 = 6H6
V_3, V_4 = 12AT7
S_1 = 1-pole 2 way
S_2 = 1-pole on-off

Power supplies. High tension rails of +230 V ar −230 V with respect to earth are required in the isograp the mean load current on each rail being about 200 mA. Tl major part of the load is that due to the cathode-follow stages. In the interests of stability and freedom from nois of the computing signals, electronically-stabilized h.t. uni are used. These are of standard design, having an intern impedance of less than 1 Ω at signal frequency; the ripp level on their outputs is of the order of 10 mV.

The coincidence transmitters were at first operated fro the laboratory 50 V 50 c/s three-phase supply, but the erro arising from unbalance effects caused by load changes prov larger than could be tolerated. Consequently an electron three-phase supply unit was built, a schematic diagram which is given in Fig. 5. The principal components of tl unit are three similar feedback amplifiers, X, Y, Z, each which is provided with scaling and phasing adjustments

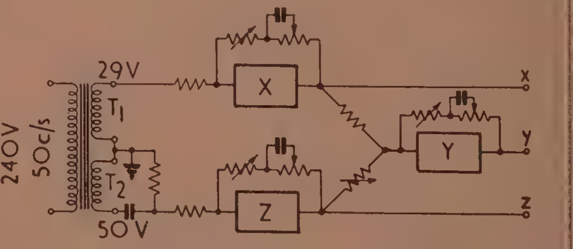


Fig. 5. Schematic diagram of three-phase, 50 c/s supply unit

s feedback path. The input voltage to X is derived from a egulated single-phase 50 c/s mains supply by means of the ansformer winding T_1. Its level is 29 V r.m.s. and its phase ngle may be taken as 0°. The output of X is at the same evel but its phase angle is 180°, this condition being achieved y adjustment of the scaling and phasing controls. The ansformer winding T_2 provides a voltage which may be pecified as 50 V $\angle 180°$. By means of the phase-shifting etwork shown, this becomes 29 V $\angle 240°$ and as such is pplied to Z, whose output is scaled and phased to be 9 V $\angle 60°$. The X and Z outputs are applied as inputs to Y, hose output is adjusted to 29 V $\angle 300°$. Thus a balanced hree-phase supply with a phase voltage of 29 V is available or the coincidence transmitters. These constitute a largely nductive load: power-factor correcting condensers, each of 6 μF, are connected in delta across the lines to them so s to offer a purely resistive load to the amplifier. Each mplifier consists of a cathode-coupled pentode pair driving pair of beam tetrodes (type 807) operating in Class AB1 nd transformer-coupled to the load. The loop gain is of he order of 300 and the amplifier is capable of giving a naximum undistorted output of about 12 W: the power equired per phase is 10·5 W. Provided that the scaling and hasing adjustments of each amplifier are carried out careully, the unbalance between the phases under normal running onditions is of the order of 50 mV r.m.s.

It is recognized that the phase-shifting network used to erive the input to the Z amplifier makes the performance of he system frequency-dependent, but the present-day stability f the mains supply is such as to introduce very little error rom this source. Since the input signals to the amplifiers are btained from an amplitude-regulated supply, the calibration f the display meter in the isograph may be depended upon or the evaluation of polynomials.

INITIAL ADJUSTMENTS

The arms of the summing network and the mechanical hasing of the magslip rotors require adjustment before the sograph is placed in service. The a_3 channel, which does not nvolve a magslip, is taken as the datum and the other hannels are balanced against it in turn. The following ettings are first made: $|r| = 1·000$, $\theta = 0°$,

$$a_1 = a_2 = a_4 = a_5 = a_6 = a_7 = 1·000, \ a_3 = -1·000.$$

The push-buttons on the display panel are then used to ompare each channel in turn with the a_3 channel, the umming amplifier being operated at its highest sensitivity. Adjustment of the variable resistance in the summing arm hould then produce a null. If this is not so, the driving gear s slackened on the hub of the magslip and the hub is rotated ntil a null is produced: the gear is then re-clamped to the ub. The magslips should not require any further attention, ut an occasional check on the adjustment of the summing rms is desirable. The push-buttons enable this to be done ery rapidly. The only remaining adjustment is that of the β-dial on the rotor of the phase-finding magslip. With the ettings given above the value of β should be 0° and the ial is adjusted until this is the case.

ROOT-FINDING WITH THE ISOGRAPH

If necessary, the equation to be solved is divided through by the greatest coefficient, so as to bring all coefficients within the compass of the isograph dials. With θ set at 0°, a search is made for positive real roots, $|r|$ being varied until a null reading is obtained on the display meter. Negative real roots may then be found in a similar fashion, θ being now set to 180°. Since the restriction $0 < |r| < 1$ is imposed on the modulus of the independent variable, an artifice is necessary to locate any roots for which $|r| > 1$. Such an artifice is the transposition of the coefficients in the equation: this follows immediately if we write $z = 1/u$, so that the equation becomes

$$a_0u^6 + a_1u^5 + \ldots \ldots + a_5u + a_6 = 0$$

This equation may now be examined for real roots in the manner described above. The range $0 < |r| < 1$ in the new equation corresponds to the range $1 < |r| < \infty$ in the original. The location of the real roots indicates how many conjugate pairs of complex roots remain to be found. Judicious exploration in θ and $|r|$ will reveal these roots, the transposition technique being again used to cover the complete range of the variable. In the case of an equation where the ratio of greatest to least coefficient is very large, a substitution of the form $v = kz$ may be employed with advantage, the constant k being selected so as to reduce the disparity in the magnitudes of the coefficients.

ACCURACY ATTAINABLE

Provided that the roots are well separated, the isograph locates them accurately and quickly. For example, the sextic equation

$$z^6 + 0·5z^4 + 0·5 = 0$$

has the following roots:—

$$\pm i; \quad 0·8409 \angle 34·65°, \angle 325·35°; \quad 0·8409 \angle 145·35°, \angle 214·65°$$

The isograph determined the roots as

$$\pm 1·003i; \quad 0·840 \angle 34·7°, \angle 325·4°; \quad 0·840 \angle 145·3°, \angle 214·8°$$

Again the equation

$$z^3 - 2·4z^2 - 1·46z - 1·02 = 0$$

has the roots

$$3·000; \quad 0·583 \angle 120·96°, \angle 239·04°$$

Herr and Graham with their isograph determined the roots as:

$$3·15; \quad 0·538 \quad \angle 125°, \angle 237°$$

The present machine found them to be:

$$2·994 \quad \angle 0·2°; \quad 0·584 \quad \angle 121·0°; \quad 0·581 \quad \angle 239·0°$$

In equations with repeated roots or with roots lying close together, the minima obtained on the display meter are broad and it is difficult then to obtain accurate values of the roots. The mathematician, solving such an equation by numerical methods, can extend his calculations to achieve any required degree of accuracy, using normal computing aids, but an isograph of given design has a limited accuracy, which must be accepted.

ACKNOWLEDGEMENTS

The authors are grateful to The English Electric Company Ltd. for permission to publish this paper. Their thanks are due also to Mr. R. J. Gomperts for many helpful discussions and to Mr. A. Hann and the late Mr. R. E. Evans for the design of the three-phase supply unit.

Angle-spring hinges

By Prof. R. V. JONES, C.B., C.B.E., F.Inst.P., Natural Philosophy Department, University of Aberdeen

[*Paper received* 28 *April*, 1955]

The hinges are based on the ease of twisting an L-section cantilever beam about its corner edge. The simplest form is easier to make, and is more compact, than a cross-strip hinge. The limitations of the angle-spring are described, and various designs of simply compensated hinges are indicated. Performance figures are given, showing that for angles of rotation up to 0·1 radian, the axis of a typical compensated hinge will remain constant within 10 μ and within 10–15″ of arc. Such hinges can be useful components in instrument design, being free from friction and backlash.

The hinges to be described are based on the ease of twisting an L-section beam about its corner edge. The simplest form of such a hinge is easier to make, and is more compact, than the standard cross-strip spring hinge; and although in this form its performance is inferior to that of the latter hinge, it is nevertheless adequate for some purposes. In a slightly more elaborate form it is comparable in performance with a good cross-strip hinge.

PRINCIPLE

Consider an angle-beam shaped as in Fig. 1(*a*). The beam is formed from a flat rectangle of spring material, bent into an L-section; its ends are strengthened by two square blocks to maintain the form of the end cross-sections as the beam is twisted about its corner edge. The lower block is used to fix the beam to a rigid base, and the upper block carries an arm on which the twisting force *F* can act; the upper block also serves as a mount for whatever component it is desired to rotate by means of the hinge.

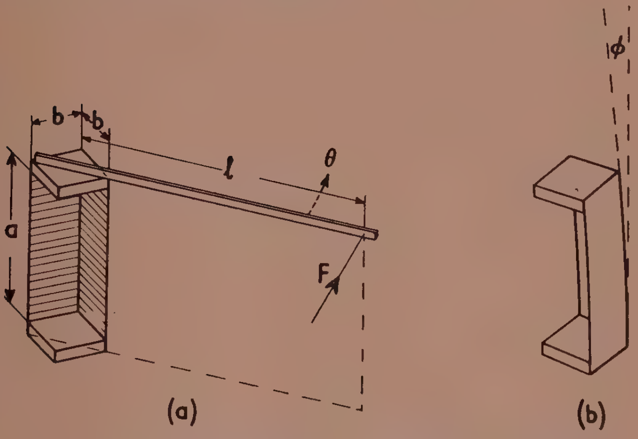


Fig. 1. Schematic diagram of simple angle-spring hinge

The first-order effect of the force *F* is to twist the beam about the edge common to its two sides. Two second-order effects also occur: (1) a bending of the beam considered as a cantilever projecting from the base, which takes place in a direction parallel to that of *F*, and (2) a warping which inevitably results from the first-order twist, and which takes place diagonally inwards from the corner edge. These second-order effects limit the performance of the system as a good hinge by causing departures from the initial axis, and a main object of the present investigation has been to elucidate the design factors which give as constant an axis as possible.

If ϕ [Fig. 1(*b*)] is the angular departure of the top surface of the upper block from its original plane for a twist of the upper block of θ (both angles in radians), the contributi of the cantilever bending to ϕ has been calculated by Dr. Strachan to be

$$\frac{2\epsilon}{(1+\sigma)}\left(\frac{c}{b}\right)^2\frac{a}{l}\theta$$

where ϵ is of the order of unity, σ is Poisson's ratio, *a* is free length of spring, *b* the length of each side, *c* the thic ness, and *l* the arm of the force *F*. This has been verifi experimentally for two different beams, varying the rat *c*/*b* and *a*/*l*.

The contribution to ϕ due to the warping effect has be investigated experimentally, and it has been found that it equal within 3% to the effect calculable by assuming t each of the free edges of the beam and the corner edge reta their original lengths, and that the corner edge remains fix in position as the beam twists. This gives the warpi contribution to ϕ as

$$\frac{b}{a\sqrt{2}}\theta^2$$

This contribution is obviously much more important th that due to bending, on account of the power of the ang By directing *F* as shown in Fig. 1(*a*), the two effects can made to oppose one another, but this is merely a palliati

Simultaneously with the variation of ϕ, there are a shifts in the instantaneous centre of rotation, due again the bending and warping. The effect of the cantilever ben ing, which increases linearly with *F*, and hence with θ, is displace the centre of rotation slightly from the corner of spring in a direction opposite to that of the arm *l*. T effect (and the corresponding effect on ϕ) can be reduced desirable by lengthening the arm *l*, since *F* will then smaller for a given rotation. The warping causes the corr of the angle-spring to track away diagonally inwards fr its original position. The displacement has been found vary rather more rapidly than θ^2 and it is a more seri effect than that due to bending, but as will be seen from performances given below it is still comparatively important.

COMPENSATION

For some applications, the variation of ϕ and of instantaneous centre does not matter. For example, a pla mirror may be conveniently mounted for rotation so that plane bisects the angle of the spring. The variation of then causes the mirror to rotate slightly in its own plane it rotates about the hinge; for a typical ratio of *a*/*b* = ϕ will change by a few minutes of arc as θ increases fr 0 to 0·1 rad. This change in ϕ is immaterial in such application.

However, there are other applications where greater onstancies of axial direction and centre of rotation are quired. Owing to the predominance of the warping effect ver that of bending, little is to be gained by varying the ickness of the spring material. The only hope is to increase e ratio a/b, but the construction becomes rather slender if is ratio exceeds ten. Other shapes of beam were tried, for xample with a tapering width from bottom to top block, ut no substantial improvement resulted over the simpler esign. It is therefore desirable to devise a compensated ovement where the warpings of two similar angle-springs re opposed when they are twisted by the same rotation.

Several possible designs have been tried in the present vestigation, and some of these are shown in Fig. 2. Each ontains two angle-springs mounted so that their warping endencies are opposed, and they all achieve a high degree of ompensation (97% or better). Designs *D* and *E* are to be referred to *A* and *B* on the grounds of a better compensation or centre drift, and design *E* is preferable to *D* in that it is mpler to make; design *D*, however, looks rather better, nd has a rather greater range of flexibility than *E*.

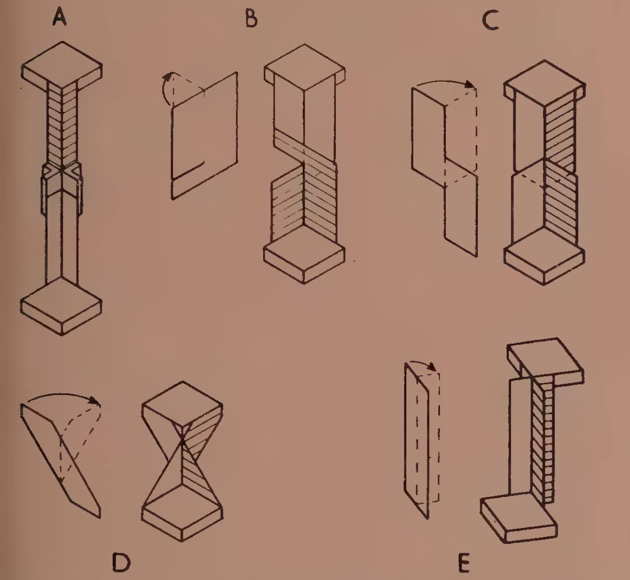


Fig. 2. Some compensated angle-spring hinges. Each hinge is made from two angle-springs, one of which is shown shaded. The ways of cutting and bending the springs are indicated

CONSTRUCTION

Beryllium–copper sheet of thickness 0·006 to 0·015 in. is itable for making the springs. Most of the designs can e simply cut on a guillotine and bent; the bend must be ade as sharp as possible without cracking, and as nearly a ght angle as possible. Most of the bends in the present vestigation have been made by hand; to minimize cracking, e material is first bent over a slightly rounded corner edge adius of curvature about 0·2 mm) of a square-section bar, nd then the resulting bend is sharpened by hammering on a arply ground edge.

The method of joining the springs to one another and to e upper and lower blocks is important. Soldering can be ite satisfactory, if care is taken not to overheat the springs and so destroy their temper. Alternatively, the springs can be clamped to the blocks by end pieces and screws.

For the most accurate assembly the end blocks should be milled or ground square, and held in jigs while the springs are attached. In many instances, however, hinges can be sufficiently well assembled using visual judgment and toolmakers' clamps; this method was used exclusively for those hinges whose performances are described in the following section.

PERFORMANCE

The maintenance of a centre of rotation was tested by finding with a toolmaker's microscope the point on the top surface of the upper block which showed minimum displacement over a measured rotation. The parallelism of the instantaneous axis of rotation to its original direction was investigated by resting a horizontal mirror on three levelling screws projecting through the top surface of the upper block, and adjusting the screws so that the mirror showed a minimum deviation from its original plane as measured by an autocollimator. Rotation was controlled by a micrometer acting through a wobble-pin on an arm attached to the upper block; this arm was usually 12 cm long, but a much shorter arm could have been used for the compensated movements without causing the hinges to bend appreciably.

For a simple angle-spring hinge with $a = 12$ cm, $b = 1$ cm, the angle of warp $\phi = 2'$ of arc, approximately, for an angle of rotation $\theta = 0{\cdot}1$ rad, ϕ being proportional to θ^2. The centre drift was about 15 μ for $\theta = 0{\cdot}1$ rad.

For compensated movements, the performance was much better. Several specimens of design *D*, for example, were made, with a spring height of 2 cm and a maximum spring width (i.e. where attached to the blocks) of 2 cm. With these dimensions, the useful range of θ ran from 0 to $\pm 0{\cdot}15$ rad; and for $\theta = 0{\cdot}1$ rad the maximum departure of the axis from its original direction, averaged over several specimens, was about 10–15″, and the corresponding drift of the centre less than 10 μ, being about 5 μ in the best specimen. Very similar performances to this were obtained with a specimen of design *E*, where each spring had $a = 6$ cm, $b = 1$ cm (in the notation of Fig. 1), and with one of design *C*. Not only are the performances much better than for the uncompensated type, but also these compensated hinges are much stronger.

The accuracy with which the compensated hinges hold their centre is impressive, and compares well with the corresponding feature of a cross-strip hinge. In fact, the centre-variation in a compensated angle-strip, for example, of design *D* is as small as that in a cross-strip hinge of less than one-fifth its linear dimensions.

The range of flexibility is limited. Obviously it increases as the springs are made longer for a given width; but, for proportions which are compatible with adequate strength ($a/b < 6$), the axis begins to depart fairly rapidly from its original direction for rotations greater than about 0·15 rad. A spring hinge of design *D* will, however, return to its original position after deflexions to more than 0·5 rad, even when the greatest breadth of the springs is equal to their length, so that the elastic limit of the system is relatively generous. The stiffness of the hinges increases with deflexion; the load increases at more than a linear rate with the deflexion, but at less than a parabolic rate. For typical hinges, the load required to produce a 0·2 rad deflexion was about three times that required for 0·1 rad. Buckling tended to occur at about 0·3 rad.

One property of the hinge which it may be desirable to know is its relative stiffness to an off-axis load on the top table, compared with its stiffness to turning about its nominal axis. This may be measured by the ratio of the angular deflexion which the torque *Fl* (Fig. 1) will produce when operating in the direction shown (i.e. with the corner edge of the spring as axis) to the angular deflexion produced by an equal torque operating about an axis perpendicular to the corner edge. This ratio has been measured for several hinges of various compensated types, and has been found to lie between 100 and 200 to 1. From rough theory, the ratio might have been expected to be more nearly 1000 to 1 for the specimens tested; the discrepancy may have been due to imperfections in construction leading to slight buckling. In operation, off-axis loads can frequently be made small, and the hinge is amply strong enough for many purposes.

The hinge has, of course, the usual advantages of a spring system in freedom from friction and backlash, and has been used satisfactorily in such applications as a bearing for diffraction grating in a small spectrometer, and as the beari for the reversing lever in a symmetrical optical slit syste It is particularly convenient in applications where the axis rotation can be situated to one side of the component bei rotated, i.e. where the component can be hinged in the sa manner as a door, since the hinge can then be made to occu merely a small volume along one side of the component.

Angle-springs can of course be made with the includ angle different from a right angle. These may be applied special purposes but in general a right angle is the corr and convenient choice.

ACKNOWLEDGEMENTS

I am much indebted to Mr. I. R. Young, who made ma measurements on the performance of various designs hinge, and to Mr. G. Watson, who constructed them.

The effect of eccentric loading of optical flats during grinding or polishing

By N. J. Rumsey, M.Sc., A.Inst.P., Dominion Physical Laboratory, Lower Hutt, New Zealand

[*Paper received* 1 *April*, 1955]

During grinding or polishing, optical flats of glass or quartz are often eccentrically loaded to modify the angle between the front and back surfaces. It is shown that if too great a loading is applied too close to the edge of the flat a kink is formed, namely, a part of the original surface remains unworked and will lie at an angle to the freshly worked part.

In order to simplify the problem, it is assumed that the forces applied to an optical flat during working are similar to those in the case of the special flat-polishing machine described by Twyman.(1) Forces required to move the flat relative to the tool are applied to the sides of the flat close to the tool so that they introduce no tendency to tip, and are irrelevant to the problem. A load is applied by a vertical weighted rod which may be placed centrally or eccentrically. (There is a backing piece between the flat and the rod, but this detail is irrelevant.) When the angle between the front and back surfaces of the flat is to be modified, the weighted rod is displaced from the centre of the flat towards the part that must become thinner.

Let the resultant of this eccentric load *L* and the weight of the flat *W* be a force *F* acting at a distance *a* from the centre of the flat, as shown in Fig. 1. The flat is maintained in equilibrium by the pressure on its lower surface. If the flat and the tool are so rigid that no detectable flexing occurs, this pressure must vary linearly across the flat, i.e.

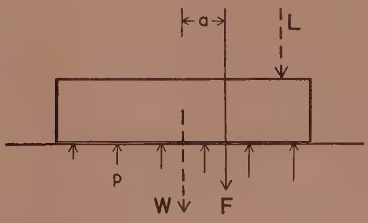


Fig. 1. Forces acting on the flat

$$p = p_0 + bx + cy \qquad (1)$$

where p is the local pressure, p_0 the pressure at the origin, b and c are constants, and x and y are the co-ordinates of the point in question. It is usually convenient to take the orig on the line of action of the weight of the flat, i.e. below t centre of gravity, and the x- and y-axes along lines of symmet of the surface being worked, if it has any such lines, or t x-axis may intersect the line of action of the applied force If F acts through the point (a_1, a_2), the equations expressi the equilibrium of the flat are:

$$\int_{x-}^{x+}\int_{y-}^{y+} p\,dy\,.\,dx + F = 0$$

Taking moments about the x-axis:

$$\int_{y-}^{y+}\left(y\int_{x-}^{x+} p\,dx\right)dy + a_2 F = 0$$

Taking moments about the y-axis:

$$\int_{x-}^{x+}\left(x\int_{y-}^{y+} p\,dy\right)dx + a_1 F = 0$$

In the case where the x-axis is a line of symmetry *and* t line of action of L intersects it, the problem is simplifie because in equation (1) c is then zero, and equation becomes superfluous.

If this case is considered when the flat is rectangular, t calculation becomes particularly simple. Let the length the flat be $2l$, and the width $2m$. Then equation (2) reduces

$$-F = 2m\int_{-l}^{+l}(p_0 + bx)dx$$

$$= 4p_0 lm$$

From equations (4) and (5):

$$4ap_0lm = -aF$$

$$= 2m\int_{-l}^{+l} x(p_0 + bx)dx$$

$$= 4mbl^3/3$$

Therefore $$b \doteq 3ap_0/l^2 \qquad (6)$$

It is desirable to have a formula giving the value of a which will result in a prescribed ratio R of maximum to minimum pressure occurring on the surface being worked. Here these pressures will be found at $x = +l$ and $x = -l$, so that:

$$R = (p_0 + bl)/(p_0 - bl)$$

$$= [1 + (3a/l)]/[1 - (3a/l)].$$

Hence $$a = \tfrac{1}{3}[(R-1)/(R+1)]l \qquad (7)$$

If it is assumed that the rate of removal of glass is proportional to the local pressure, this formula conveys much useful information.

One point to note is that small values of a correspond to surprisingly large values of R. For example, if the pressure at one end of the flat is to be made four times that at the other, $a = 0{\cdot}2l$. This value of a is only one-tenth of the total length of the flat!

The most important case arises when the angle between the surfaces of the flat is to be changed without removing glass unnecessarily. Here the pressure should reach zero at the end of the flat where no glass need be removed. Then $R \rightarrow \infty$, and $a = \frac{1}{3}l$. (Note that this also means that the force F is acting through a point one-third of the distance from the high pressure end to where the pressure has become zero.)

It is interesting to consider what happens when a is allowed to become greater than $\frac{1}{3}l$. The mathematics suggest that the pressure becomes negative at the low-pressure end. This would correspond to *addition* of glass there during working. In practice, of course, this does not happen. Actually, the pressure drops continuously from the high pressure end until it reaches zero at a point three times as far as the line of action of the force F from the high pressure end, and thereafter remains zero. For example, if $a = \frac{1}{2}l$ the pressure will be zero from $x = -\frac{1}{2}l$ to $x = -l$. If a flat is worked under such a condition its surface develops a kink at $x = -\frac{1}{2}l$ because no glass is removed from there to $x = -l$, while a linearly increasing amount is removed from $x = -\frac{1}{2}l$ to $x = +l$, as shown in Fig. 2.

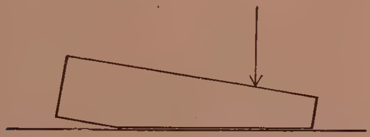


Fig. 2. Behaviour of a flat loaded too eccentrically

[My colleague Mr. Aspden points out that such an effect is well known in the spectacle lens-making trade. If an inexperienced operator is told to reduce the amount of "prism" on a lens, he almost invariably produces a kinked surface through applying pressure too near the edge. Mr. Aspden (using a fine abrasive) has also ground a rectangular slab of glass under the conditions described at the end of the previous paragraph and confirmed the conclusion as precisely as our accuracy of measurement allows.]

Any reader who is familiar with the subject of *Strength of Materials*⁽²⁾ may have realized by now that the problem is formally identical with that of eccentrically loaded short columns weak in tension. Therefore the calculations for this and other cases may be found elsewhere, and further results will merely be quoted here.

When the force F acts through a point (a_1, a_2) of a rectangular flat of the dimensions previously assumed, equation (1) becomes:

$$p = p_0\left(1 + \frac{3a_1x}{l^2} + \frac{3a_2y}{m^2}\right) \qquad (8)$$

Assuming for the moment a_1 and a_2 are positive, the pressure at the corner $(-l, -m)$ of the flat will have fallen to zero if (a_1, a_2) lies on the line joining $(\frac{1}{3}l, 0)$ and $(0, \frac{1}{3}m)$. Thus if a kinked surface is to be avoided, the line of action of F must be confined within a rhombus, the diagonals of which lie along the lines of symmetry of the rectangular surface and have lengths one-third of the length and of the width of the rectangle.

In the case of a circular flat of radius r,

$$a = \tfrac{1}{4}[(R-1)/(R+1)]r \qquad (9)$$

and the maximum permissible value of a is $\frac{1}{4}r$.

In the case of a very narrow annular surface of mean radius r,

$$a = \tfrac{1}{2}[(R-1)/(R+1)]r \qquad (10)$$

and the maximum permissible value of a is $\frac{1}{2}r$.

In the case of an annular surface with inner and outer radii r_i and r_0,

$$a = \tfrac{1}{4}[(R-1)/(R+1)]\,[(r_0^2 + r_i^2)/r_0] \qquad (11)$$

and the maximum permissible value of a is $\frac{1}{4}(r_0^2 + r_i^2)/r_0$. The two preceding cases may be considered as special cases of this, with $r_i = 0$ and $r_i = r_0$ respectively.

In order to ensure that the force F does not act too far from the centre of the flat, it is probably desirable that the backing piece attached to the flat be so shaped that the external load L cannot be applied at greater distances than the maximum permissible value of a worked out above. On the other hand, this arrangement would require values of L greatly exceeding the weight of the flat W to produce the most efficient conditions for changing the angle between the front and back surfaces, and such a loading may well be considered excessive. If, however, the loading is reduced by permitting a smaller L to act near the edge of the flat, great care must be taken to ensure that its value does not exceed an appropriate fraction of W; e.g. in the case of a circular flat, $L \leqslant \frac{1}{3}W$.

ACKNOWLEDGEMENTS

The author is indebted to Mr. R. Aspden for suggesting the investigation and for the experimental verification mentioned above, and to Mr. R. I. Skinner for discussion.

REFERENCES

(1) Twyman, F. *Prism and Lens Making*, 2nd ed., pp. 318–322 (London: Hilger and Watts Ltd., 1952).

(2) See, for example, Timoshenko, S. *Strength of Materials*, Part I, 2nd ed., pp. 230–239 (New York: D. van Nostrand Co., Inc., 1940).

Portable radiation detectors employing photoconductive cells

By J. C. S. Richards, B.Sc., Ph.D., Department of Natural Philosophy, University of Aberdeen

[*Paper first received* 22 *April, and in final form* 16 *June*, 1955]

The difficulties inherent in the design of small portable, battery-powered, infra-red detectors employing photoconductive cells are discussed, with particular reference to the signal-to-noise ratio of suitable electronic amplifiers, and the method employed to "chop" the radiation. The main novelty is the use of an electromagnetically-maintained vibrating leaf-spring with a shutter suitably mounted at its free end as a radiation chopper. The design and applications of this device are discussed in some detail.

The development of photoconductive cells using various semi-conducting salts of lead has greatly simplified the problem of detecting infra-red radiation. It is now feasible to use in the field many techniques of measurement previously confined to the laboratory. In this paper are discussed the problems arising in the design of portable infra-red detectors powered from primary batteries.

THE CHOPPING DEVICE

To reduce the effect of "current" noise in these cells, it is usual to "chop" the incident radiation at a frequency of about 800 c/s, but a reduction of frequency by a factor of four (say) only halves the signal-to-noise ratio. In mains-powered apparatus, a sector disk driven by a synchronous motor is generally used as a chopper; the chopping frequency is thereby held constant and a sharply-tuned amplifier can be used with the detector. In battery-powered apparatus the motor must have some form of automatic speed control (or have its speed checked frequently) and suitable motors draw a relatively large amount of power from the battery. The sectored disk is of necessity much larger than the opening for which it is to act as a shutter, and it is often difficult to incorporate it in the optical system of (say) a very small spectrometer.

The chopping device to be discussed is shown schematically in Fig. 1. A shutter *R* is carried on the end of a lever arm *Q* which is rigidly fixed to one end of a metal leaf spring *S*. The other end of the spring is clamped in a rigid support *P*. When the spring executes transverse vibrations, the shutter *R* is moved in and out of the beam of radiation, thus "chopping" the light. The oscillations of the system are maintained by the means devised by Eccles⁽¹⁾ for maintaining a tuning fork in vibration.

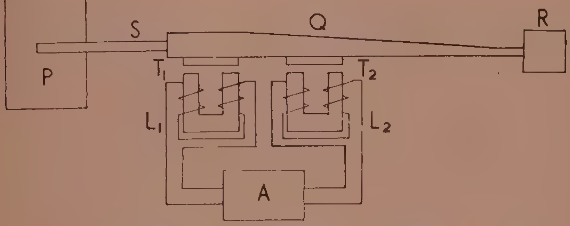


Fig. 1. General arrangement of radiation chopper

P, supporting structure; *S*, leaf spring; *Q*, lever arm; *R*, shutter; T_1, driving coil armature; T_2, pick-up coil armature; L_1, driving coil; L_2, pick-up coil; *A*, electronic amplifier.

At a convenient position on the moving system is mounted a pair of soft iron armatures T_1 and T_2. Adjacent to T_1 an iron-cored coil L_1, referred to as the driving coil. Adjacen to T_2 is another iron-cored coil L_2, referred to as the pick-u coil. The cores of both coils carry a steady polarizin magnetic field. Any motion of the armature T_2 induces i the pick-up coil L_2 an e.m.f. which is amplified by the amplifie *A* and fed to the driving coil L_1. If the amplifier gain sufficient, and the sense of the coil windings and polarizin fields correct, the system is maintained in vibration at th resonant frequency of the mass loaded spring. This metho of driving the reed eliminates contacts with their tendency t spark and corrode.

Not only is this oscillating chopper lighter, smaller an more easily powered than a motor-driven sectored disk, bu it has the additional advantage of providing, at either th pick-up or driving coil, an e.m.f. of the same frequency a and in fixed phase relationship to the chopped radiatio reaching the photoconductive cell. This e.m.f. may b used as a reference signal in a coherent detector. Th advantages of a coherent detector have been discussed b Smith.⁽²⁾

DESIGN CONSIDERATIONS

The power necessary to maintain the oscillating choppe in vibration is $K\delta\omega/\pi$ where K is the kinetic energy of th chopper, ω is the angular frequency, and δ is the logarithm decrement of the chopper when in free vibration (but wit pick-up and driving coils in position). To minimize K th inertia of the moving parts must be kept as small as possibl subject to the condition that the frequencies of any flexur modes of vibration they may have must be greater than th chopping frequency. If a steel spring is used, separat armatures may be dispensed with, as in the design shown i Fig. 3. The ideal lever arm would probably be a tapere Duralumin rod of hollow elliptical or I-section, but such a arm is difficult to fabricate and cannot be readily welded soldered to the spring.

Once the general type of design is decided, the width an thickness of the spring may be adjusted to give the corre frequency of vibration.

The value of the logarithmic decrement of the loade spring depends on (1) the purely mechanical, and (2) th electromagnetic damping. The sources of mechanic damping have not been investigated in detail, but it appea that steel springs give better performance than berylliu copper or phosphor-bronze, and that any joints between th various components of the vibrating system should be a rigid as possible. The block to which the spring is clampe and the whole coil assembly should be as massive and rig as practical.

The motion of the armatures in the steady polarizin iagnetic fields gives rise to an alternating component of flux the magnetic circuit, and consequently power is dissipated y eddy currents and hysteresis in the magnetic materials, and y any current caused to flow in the coils. Obviously the oils should be designed to have as high a quality factor or "Q") as possible when in position and connected to the mplifier. In practice, the major part of the losses arises rom eddy currents, and, if possible, powder or ferrite cores hould be used. Ferroxcube made by Mullard Ltd. is a uitable soft magnetic material, and Gecalloy made by alford Electrical Instruments Ltd. is a suitable permanently iagnetic material.

Since the power lost by electromagnetic damping in the riving coil increases as the square of the polarizing field, nd the driving force is proportional to the polarizing field, here is no advantage to be gained in making the polarizing ield very large unless the electromagnetic damping losses re kept small. In a well-designed system the mechanical nd electromagnetic damping should be of the same order f magnitude.

Driving amplifiers. Unless the oscillating chopper is very arge or very inefficient, a single pentode or tetrode valve such as the Mullard type DL92 or the Brimar type 3S4) ives sufficient gain and power output to maintain oscillations t a suitable amplitude. The reference signal for a phase-ensitive detector may be taken from the anode of this valve, ut a separate valve is usually necessary to obtain sufficient ower to operate the detector.

In considering the working conditions of the driving valve, he impedance of the driving coil may be considered as an nductance L in parallel with a resistance R, the whole in eries with a suitable circuit representing the effect of motion f the driving coil armature. This motional impedance is liscussed by Butterworth,(3) but it is generally small comared with the resistance of the coil and may be neglected. From the point of view of efficiency the motional impedance hould, of course, be large compared with the purely electrical mpedance of the coil, but this is difficult to achieve with a ystem of small size.) In practice, the magnetic circuit of he coil and the winding area are largely fixed by consideraions of available space, mechanical design, etc., and the coil an be given a suitable impedance to suit the driving valve y choosing the number of turns of wire correctly.

Butterworth(4) has considered the effect of connecting apacitors across the pick-up and driving coils on the ease vith which oscillations are maintained. He concludes that is advantageous to tune both coils to resonance, in which ase the system operates most effectively if the coils are onnected to the amplifier in the sense opposite to that equired to give oscillations when no tuning capacitors are resent. Tuning the coils gives several additional advantages. l) Oscillations arising from purely electrical coupling between ie coils are inhibited, since such oscillations tend to occur t frequencies much greater than the chopper frequency. 2) The waveforms of the e.m.f.'s across the coils are made iore sinusoidal, and hence more suitable as reference signals. 3) The load on the driving valve becomes a tuned circuit, nd class AB working is possible.

The discussion of driving amplifiers using thermionic alves applies with slight and obvious modification to mplifiers using transistors. The transistors at present vailable in this country have relatively low values for collector issipation. A small chopper (shown in Fig. 2) has been run rom a two-stage amplifier using Mullard OC71 junction ransistors, but only by exceeding the maker's dissipation tings. The e.m.f. from the pick-up coil is fed directly to the base of the first stage transistor, which has a resistor on its emitter lead to give a high input impedance. The output stage is in the grounded emitter configuration and the base is directly connected to the emitter of the first stage. The reference signal is derived from a transformer in the lead to the collector of the first transistor.

PARTICULAR CHOPPERS

In the preceding sections of this paper, some of the more important factors affecting the design of choppers have been indicated. In practice, the design of a particular chopper is often determined to a certain extent by considerations other than those discussed; in particular, the space available for mounting the chopper, and the ease of fabricating certain components. Two choppers will now be described in some detail; neither represents an ideal design, although both perform adequately their appointed function.

A small chopper. This chopper is shown in Fig. 2. The shutter moves in front of the entrance slit in a sub-miniature spectrometer, and a peak-to-peak amplitude of 0·8 mm at a frequency of 300 c/s is adequate. The general design was fixed almost wholly by the space available to contain the chopper. The essential components, other than the lever arm, occupy a volume less than 3 × 3 × 3 cm. The driving and pick-up coils are mounted side by side, and pot-type cores are used to minimize the direct-electromagnetic coupling between the coils and to simplify the problem of screening the photocell.

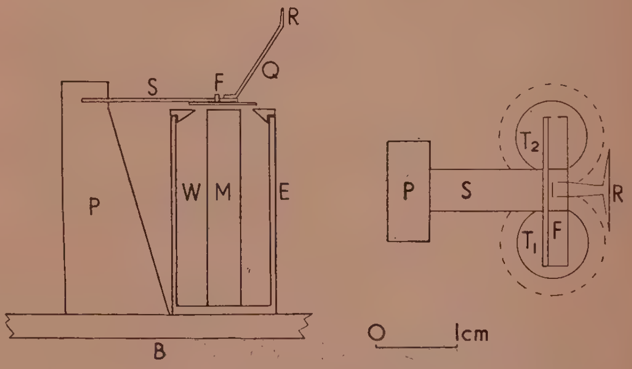


Fig. 2. Side and plane view of chopper for very small spectrometer

B, brass base; *P*, brass support for spring; *S*, beryllium copper spring, 0·4 mm thick; *Q*, lever arm of U-section with shutter *R*, both fashioned from a single piece of 0·05 mm thick brass foil; *F*, brass cross-piece of L-section, fashioned from 0·2 mm brass foil; T_1 and T_2, driving and pick-up armatures of 0·25 mm Stalloy; *E*, mild steel pots for coils; *M*, centre core, mild steel for driving coil, magnetized cobalt steel for pick-up coil; *W*, coil winding, 10 000 turns of 47 s.w.g. enamelled copper wire for each coil; inductance 1·1 H (approximately), resistance 2 kΩ.

The pot cores are made with mild steel as a soft magnetic material, and the magnetic circuit of the pick-up coil includes a cobalt steel permanent magnet. This buzzer is very easy to fabricate as all components can be turned or ground, and all joints soldered, but the eddy current losses are large because of the low resistivity and lack of subdivision of the coil cores.

The polarizing field for the driving coil electromagnet is provided by the steady component of the anode (or collector) current in the output valve (or transistor) of the driving amplifier. The optimum value of this current is between 5 and 7 mA. Any appreciable increase in current leads to a decreased efficiency because of the increased eddy current damping.

A medium size chopper. A chopper giving a shutter amplitude of about 1 cm at a frequency of about 250 c/s is shown diagramatically in Fig. 3. The shutter moves directly in front of the sensitive area of a lead telluride cell, and a long lever arm is used to give sufficient amplitude of vibration, and to make the separation between the driving coils and the photocell as large as possible. U-shaped cores are used for the driving and pick-up coils. These cores have Ferroxcube legs and the U-shape is completed by a Gecalloy permanent magnet fixed between the legs. The nature of the core materials ensures that the eddy current losses are small. The driving coil winding is made in two equal halves, one in each leg of the core. The pick-up coil is mounted in the position as shown in Fig. 3 so that the direct electromagnetic coupling is very nearly zero, despite the lack of screening between the pick-up and driving circuit.

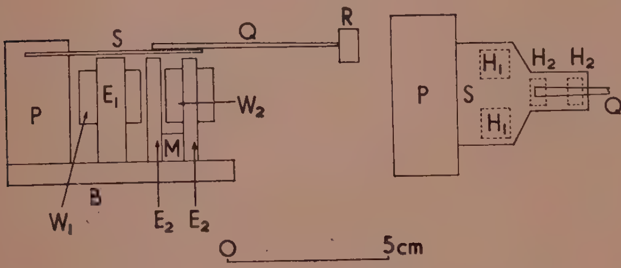


Fig. 3. Side and plane view of medium-size chopper

B, brass base; *P*, Duralumin support; *S*, steel spring, 0·85 mm thick; *Q*, lever arm of tapered V-section, fabricated from 0·25 mm shim steel; *R*, brass shutter 0·05 mm thick; E_1, rectangular Ferroxcube core legs for driving coil, approximately 1 × 1 cm section; E_2, rectangular legs for pick-up coil, approximately 1 × 0·5 cm section; *M*, Gecalloy permanent magnet; W_1, driving coil, 7000 turns of 44 s.w.g. enamelled copper wire wound in two sections, one on each leg of the core; inductance 2·5 H (approximately), resistance 1·2 kΩ; W_2, pick-up coil, 17 000 turns of 48 s.w.g. enamelled copper wire, inductance 18 H (approximately), resistance 9·5 kΩ; H_1, position of ends of driving coil core; H_2, position of ends of pick-up coil core.

To reduce the mass and simplify the construction of the moving parts, the steel spring itself provides both the pick-up and driving coil armatures. If the driving coil is tuned by a suitable capacitor any valve which will operate with a mean anode voltage of about 70 V and a mean anode current of about 5 mA may be used to drive the coil. The coil should be connected so that the steady component of anode current produces a polarizing field in the same sense as that due to the permanent magnet.

PHOTOCELL AMPLIFIERS USING THERMIONIC VALVES

The design of the photocell amplifier and detector follows standard practice. The main difficulty is to keep the equivalent noise resistance of the input stage sufficiently low. Although the ohmic resistance of the cell may be as low as 50 kΩ at room temperature, the equivalent noise resistance is likely to be several times this value at 200 c/s.

Most battery valves sold as audio voltage amplifiers ha a low mutual conductance, and their equivalent noise res tance calculated from the usual formulae (e.g. see Terman(is of the order of 50 kΩ. Eight specimens of a typical val (Mullard type DAF91) were tested; five of these were fou to have equivalent noise resistances at 200 c/s of betwe 200 and 300 kΩ; for the remaining three the values we greater than 1 MΩ. Selected specimens of this valve a therefore just usable in the input stage, but it is probab advisable to use a valve with higher mutual conductanc The Mullard type DF62 subminiature pentode, when run a grid bias of −1·5 V and with the anode and screen gr at about 40 V, has an equivalent noise resistance of less tha 15 kΩ. In addition, its relatively thick filament (it requir 100 mA, 1·25 V) ensures that it is comparatively free fro low frequency microphony. It is usually necessary to r the filaments of the early stages from a separate battery prevent feedback *via* the filament resistance.

Although ideally it is unnecessary to use a tuned amplifi preceding a phase-sensitive detector, some limitation amplifier bandwidth is advisable to prevent cross modulati in the output stages. A tuned choke or transformer in o of the valve anodes forms a convenient filter; slight mistuni may be used to compensate for any undesirable phase chang occurring elsewhere in the system. The phase-sensiti detectors described by Tucker(6) (with crystal rather tha thermionic rectifiers) are very suitable.

AMPLIFIERS USING TRANSISTORS

The main objection to using the transistors at prese available in place of valves in the amplifier, is that they a noisier and have lower values of permitted power dissipatio This tends to make the transistors unsuitable for input a output stages, and it is scarcely worth while using them f the intermediate stages only. An amplifier has, howeve been made using Mullard type OC70 and OC71 transisto it gives sufficient output to feed a phase-sensitive detect working into a 0–100 microammeter.

Since the input impedance of the amplifier is of the ord 600 Ω, a step-down transformer, which must be careful screened from the chopper coils, is used to match the phot cell to the amplifier. The noise figure for a type OC transistor is about 12 dB. The noise figure of a typical c at room temperature is also of this order of magnitude, that with the transformer ratio chosen for maximum pow transfer, the signal-to-noise ratio is about 3 dB less than would be with an ideal amplifier.

If the cell is cooled by liquid air, it is essential to use valve amplifier. Not only does the noise generated by t cell decrease, but the ohmic resistance of the cell becomes large (10 MΩ say) that it is difficult to design a suitab matching transformer.

CONCLUSIONS

The problems, the solutions of which have been indicate were the principle ones that arose in the design of (1) t non-optical part of a sub-miniature portable spectromete and (2) a detector for use in field studies of naturally occurri infra-red radiations. It is clear that by using suitable tec niques it is not difficult to make a compact portable, infra-r detector which can be powered from batteries. In no portable apparatus, the use of batteries may be advantageo n circumstances where mains-borne interference is difficult o eliminate.

The main novelty in the paper is the use of a vibrating reed o chop the radiation in place of the usual rotating disk. In nains-powered apparatus, the oscillating chopper has the dvantage that, in general, it is much more easily incorporated in the optical system. This is particularly the case vhere the chopping frequency is slow (say 5 to 20 c/s for a hermally-operated detector), for then a very long lever arm nay be used without difficulty. For example, many laboratories have available a general purpose infra-red detector vhich is not incorporated in any specific apparatus. In this, thermopile or bolometer is mounted at or near the focus of a parabolic or spherical mirror. Unless the mirror is xceptionally large (or exceptionally small) a conventional ectored disk reduces the effective area of the mirror considerably. To prevent this a more elaborate arrangement of nirrors (such as the Newtonian system) may be used, but an scillating chopper with a long lever arm forms a more onvenient solution.

ACKNOWLEDGEMENTS

My thanks are due to Professor R. V. Jones, whose work on sub-miniature spectrometers initiated this paper; and to Mr. W. M. Stratton, who constructed most of the experimental choppers and amplifiers.

REFERENCES

(1) Eccles, W. H. *Proc. Phys. Soc.* [*London*], **31**, p. 269 (1919).
(2) Smith, R. A. *Instn Elect. Engrs Monogr.* No. 6 (1951).
(3) Butterworth, S. *Proc. Phys. Soc.* [*London*], **27**, p. 410 (1915).
(4) Butterworth, S. *Proc. Phys. Soc.* [*London*], **32**, p. 345 (1920).
(5) Terman, F. E. *Radio Engineers Handbook*, 1st ed., p. 294 (New York: McGraw-Hill Book Co., Inc., 1943).
(6) Tucker, M. J. *Electronic Engng*, **21**, p. 239 (1949).

An automatic sample changer for radiometric work

By J. Rydberg, Ph.D., Research Institute of National Defence, Dept. 1, Sundbyberg 4, Sweden

[*Paper received* 10 *December*, 1954]

A simple, self-contained, automatic sample changer has been constructed, which can be used together with all common types of radioactivity pulse counters. The construction permits a simple exchange of the detector (for either α, β or γ counting) and allows repeated measurements for a predetermined time (1 s to 10 days) or pre-determined count (N to $10^5 N$, where N is the scaling factor) for up to twenty-four different samples. Data for absorption curves as well as back-scattering curves can be obtained automatically.

Vhere radioactive tracers are used on a large scale, as, for nstance, in chemical and medical research, a need for automatic counting equipment soon develops. Though many ifferent automatic sample changers have been constructed, nost of them are only made to fit into a certain combination f detector, scaler, register, etc. However, at most places vhere an automatic sample changer is needed, some counting quipment already exists, and the specification on the counting quipment may be different at different places and also vary rom time to time. Since this was the case at this Institute, n automatic sample changer was constructed. It is a self-contained unit and can be used together with most kinds of ommercially produced scalers, registers, etc. Due to its high exibility, accuracy and relatively low cost of construction, he changer is believed to meet most demands encountered in hysical, chemical and medical radiometric work. The two nits, which have been built at this Institute, have been in se for more than a year without any failure. A description f the apparatus is given below.

GENERAL FEATURES

Fig. 1, a block diagram, shows the different units, which are necessary for the functioning of an automatic sample changer. The sample changer itself consists of the mechanical sample changer F and its operating unit G. It is connected to an ordinary scaling instrument A, B, the counting tube C of which is situated in the lead shield of unit F. Accurate timing is obtained from a time signal generator D, which provides pulses at constant frequency. The registration of the number of counts for a predetermined time, or time for a predetermined number of counts, is done on the register E.

The sample changer. The radioactive samples, which usually arrive in cups of stainless steel (p, Fig. 2), are placed in special sample holders q, which then in turn can be placed in some of the twenty-four holes of the large sample disk h, where they rest on solenoidal springs r.

When a sample is going to be measured, the sample disk h rotates until it stops with the sample below the lead shield (C in Fig. 1, k in Fig. 2). Then a lead plunger g moves up from below through the hole in the sample disk, takes the sample holder on its upper surface and transports it up to the detector, which is situated in the upper part of the lead shield. In this position the distance between the detector

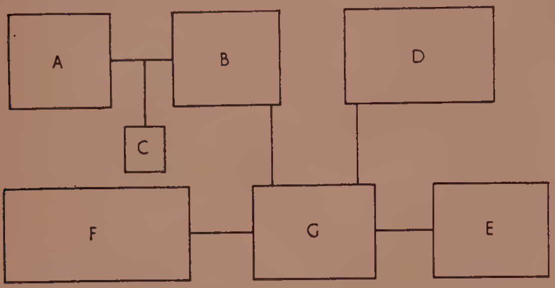


Fig. 1. Block diagram of the main units of the automatic sample changer

and the sample to be measured is a few millimetres, while the distance to a sample outside the lead shield is at least 7 cm, of which at least 3 cm are lead. Since the inner diameter of the spring is less than the diameter of the plunger, it must expand around the plunger, while the latter forces its way up.

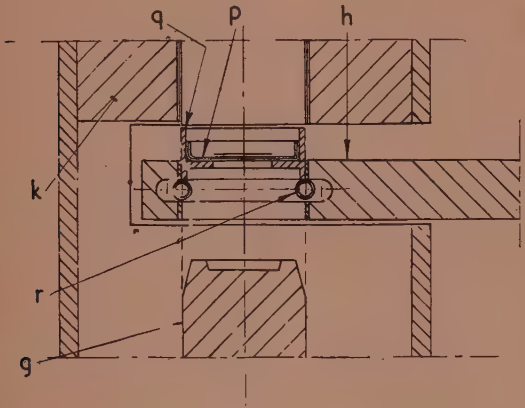


Fig. 2. The arrangement of the sample holders

The movements of the sample disk and the lead plunger are synchronized in such a way that the sample disk only moves when the lead plunger is in its lowest position, and the lead plunger only moves when the sample disk stands still with one of its holes in line with the plunger. A micro-switch (SW_8, Fig. 3) is used to indicate when the lead plunger has brought a sample holder to its top position, and thus a sample is ready to be measured. If no sample holder is brought up, the switch is not actuated. Another micro-switch (SW_9) indicates when the lead plunger is in its bottom position, and the sample disk can be freely rotated around its axes.

The radioactivity measuring units. Different kinds of radioactivity detectors may be used with the sample changer, depending on the kind of particles to be counted. A change from one kind of detector to another is very simply made. The upper part of the lead shield, which contains the detector, can be removed simply by lifting it up, and another kind of detector put in its place.

The functioning of the automatic sample changer puts no special requirements on the high voltage unit or the scale Apart from connexions for an external register, two oth connexions are required: one for an external "on-off" coun ing switch, and another for external "reset" of the inte polation lamps. These two connexions are easily made c scalers, which do not ordinarily have them.

Time signal generator. Any device which can regular deliver one signal per second may be used. If possible t signals should be of approximately the same size and sha as those from the scaling unit *B* (Fig. 1). In countries whe the alternating current of the electric power mains is frequenc stabilized, a simple time signal generator can be made fro a synchronous motor, a relay, and a d.c. supply to power t timing pulses. More exact but also more expensive devic may be used, e.g. a quartz crystal clock, a pendulum cloc an oscillating circuit, a tuning fork circuit, etc. The thr latter devices have been successfully used at this Institute.

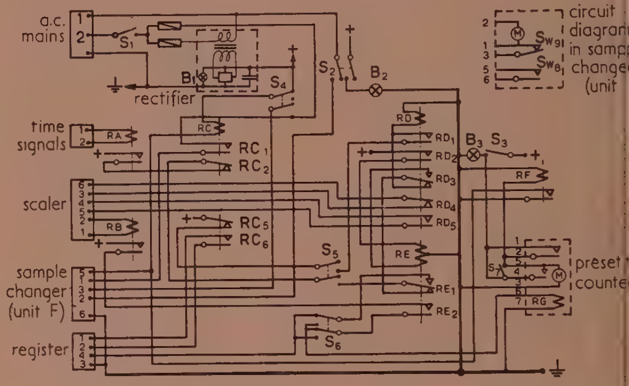


Fig. 3. Circuit diagram of the operating unit

The operating unit. The circuit diagram of the operatir unit is given in Fig. 3. It consists mainly of a rectifier, s relays (*RA–RF*) and the preset counter. The rectifier giv a direct voltage of 24 V, which operates the coil *RG*, t resetting motor of the preset counter and the coils of all oth relays except *RA* and *RB*.

The relays *RA* and *RB* are actuated by pulses from t time signal generator and the scaler, respectively. These tw relays can be chosen so that they will be operated by puls of any amplitude between 10 and 300 V and a length of least a few milliseconds; this will be sufficient for most kin of scalers and time signal generators.

S_1 is the main power switch. There are two controls and S_4 for manoeuvring the sample changer (unit *F*). S_2 the power switch for the motor of the sample changer. T switch S_4 controls the position of the lead plunger (*g*, Fig. in the sample changer. In Fig. 3, S_4 is in the "measuri position," which means that the plunger is in its top positic with a sample ready for being counted. When S_4 is switche over into the opposite position ("loading position") t current through the motor closes through the microswit SW_9, and the plunger moves down until SW_9 breaks t motor current. The plunger is then below the surface of t large sample disk (*h*, Fig. 2), which can then be freely rotate if its locking pin is lifted.

The diagram in Fig. 3 shows the operating unit in a positic ready to start registration with S_6 on "preset coun (provided that S_1, S_2 and S_3 are closed). S_5 is the "sta stop" switch. A closing of S_5 results in the actuation of R by the first time signal which arrives from *RA*. This caus

RD to close in a self-locking manner over RD_1. When RD_2 loses, current starts to flow through one of the two oppositely vound coils of relay *RE*. However, the current from the ime signal is switched over at RD_3, so that it flows through he other winding of coil *RE*. The two opposite currents ompensate each other, so that the relay *RE* is not actuated intil the time signal current through *RA* stops. This marks 'time zero,'' and pulses from the scaler will start to pass to he preset counter over *RB*, RE_2 and S_6. All the subsequent ime signal pulses will pass to the register over *RA*, RC_2, S_5, RE_1 and S_6. The complicated arrangement with relays *RD* nd *RE* is necessary if the first time signal pulse is not to be ecorded, since the time signal pulses are usually of longer luration than the time required for actuating a relay.

Registration proceeds until the preset count is reached vhen the contacts 1–2 of the preset counter are closed. This starts the resetting motor, which almost immediately loses the contacts 4–5 and releases the contacts 1–2. The esults of this are: (*a*) *RF* is actuated, which (*b*) makes current low through *RC*, which in turn (*c*) cuts off the current hrough *RD* at RC_5 and (*d*) consequently also that through RE. The contact RC_2 for the pulses from *RA* (i.e. the time ignal generator) and the contact RE_2 for the pulses from RB (i.e. the scaler) are broken and the contacts for starting nd resetting the register (RC_6) as well as stopping (RD_4) and esetting (RD_5) the scaler are closed or broken. (Depending n the makes of the register and scaler another combination f contacts for stopping, registration and resetting may be eeded.)

In addition, the contacts at RC_1 close so that current starts o flow through the motor of the sample changer (unit *F*, ontacts 1–2), and the lead plunger starts moving down. Now SW_8 closes, which keeps *RC* actuated independent of RF. In the meantime the preset counter has been reset, its ontacts 4–5 have been broken and the current through *RF* s cut off. However, not until the plunger has reached its op position again (together with a sample holder), does SW_8 reak the current through *RC*. The operating unit is then ack to its starting position.

The time for changing a sample is about 5–10 s, while the ime for the automatic resetting to the preset count is about s. The preset counter is made commercially (type TiF5P1E, ociété des Compteurs de Genève, Geneva), and any figures etween 99·999 and 1 can be preset; the manual setting of certain preset value is very simply made and takes only a ew seconds. Its registration relay *RG* can count up to 5 pulses/s.

Register. A commercially made register with printing and esetting device is probably the most convenient type, provided hat high speed counting (greater than 10 counts/s from the caler output) is not required. The time for printing and esetting of these registers is practically always smaller than he time for sample changing, and is of the order of 2–3 s. wo different makes (type SCIA-R, Streeter–Amet Co., hicago, U.S.A.; type F 272, Irion and Vosseler, Schwen-ingen am Neckar, Germany) have been successfully tested or a long time.

A register built from twenty-four ordinary telephone egisters and a 25-way telephone line selector have also been sed. This register only allowed one complete cycle of the arge sample disk, since the twenty-four individual registers ad to be reset manually. The advantage of this type of register over the printing-resetting-type is limited to the fact that it is less expensive and permits a faster change from one register to another (about 0·07 s). This makes it useful for measuring fairly short half-lives. Other registers than ordinary telephone counters have to be chosen if a higher counting speed than 25 counts/s is expected from the output of the scaler.

GENERAL PROPERTIES OF THE AUTOMATIC SAMPLE CHANGER

For any sample or samples, the sample changer can be set (switch S_6) to register the number of counts in a predetermined time from 1 s to 1 day (if the time signal generator in addition to 1 pulse/s can deliver 0·1 pulse/s; the predetermined time can be extended to 10 days) or the time for a predetermined number of counts between N and $10^5\,N$, where N is the scaling factor of the counting circuit.

The sample changer can be loaded with up to twenty-four samples, which are placed in special sample holders (*q*, Fig. 2). If the operating unit is set on sample changing (switch S_2) and automatic registration (switch S_3), these samples will be measured in the predetermined way until they are manually stopped (switch S_5). The sample disk may thus make several revolutions. For each revolution, the radioactivity of a sample at a certain counting time is registered. The data obtained after a sufficient number of revolutions gives the decay curves for the samples. Measurements will only be made on those of the twenty-four positions of the sample disk which contain sample holders. Other positions will be passed over without any measurement or registration.

It is more usual that a decay curve is wanted for only one sample. The sample changer is then loaded with this sample in the ordinary way, but before the "start"-switch is put on, switch S_2 is turned off. This prevents sample changing and the registration of the radioactivity of the sample will occur at predetermined intervals, until manually stopped (switch S_5).

For the measurement of absorption curves, the sample is put in the recess on top of the lead plunger (*g*, Fig. 2), while the absorbers are placed in the sample holders (*q*, Fig. 2) on the sample disk. The activity transmitted through the different absorbers will then be registered during a predetermined time or number of counts. With the present design the maximum thickness of the absorbers is 5 mm.

Backscattering effects have also been measured with the instrument. The sample (a point source) was placed on a thin film below the surface of the detector. The lead plunger was exchanged for a thin-walled Perspex plunger. Different backscattering materials of various thicknesses were placed in the sample holders (*q*, Fig. 2). The sample changer could then be run on a predetermined time or count basis.

ACKNOWLEDGEMENTS

The author wishes to thank the head of the Research Institute of National Defence, Dept. 1, Professor G. Ljunggren, for his kind interest in this work, and Mr. P. Clementz for the construction of the mechanical sample changer (unit *F*).

Oscillographic measurement of the Penning-gauge characteristics

By M. Varićak, M.Sc., The Institute of Physics, Faculty of Science, Zagreb, Yugoslavia, and B. Vošicki,
The Ruder Bošković Institute, Zagreb, Yugoslavia

[*Paper received* 31 *January*, 1955]

To investigate the performance of a Penning-type vacuum gauge, deflexions proportional to its current were displayed on an oscilloscope screen, while the magnetic field in the gauge was linearly varied. Such a field was produced by an electromagnet, which was part of a linear time-base circuit. From the patterns observed at different pressures and voltages across the gauge, best working conditions could be quickly obtained.

The optimum operating characteristics of the Penning-type cold cathode ionization gauge⁽¹⁾ depend not only on the anode voltage and the magnetic field strength⁽²˒³⁾ but also on the geometrical configuration and dimensions of the electrodes.⁽⁴⁾

The aim of this paper is to describe a simple method of obtaining on the screen of an oscilloscope a series of curves showing the dependence of the discharge current on the strength of the magnetic field. From these oscillograms, observed at different pressures and at different values of anode voltage, optimum working characteristics could be easily determined.

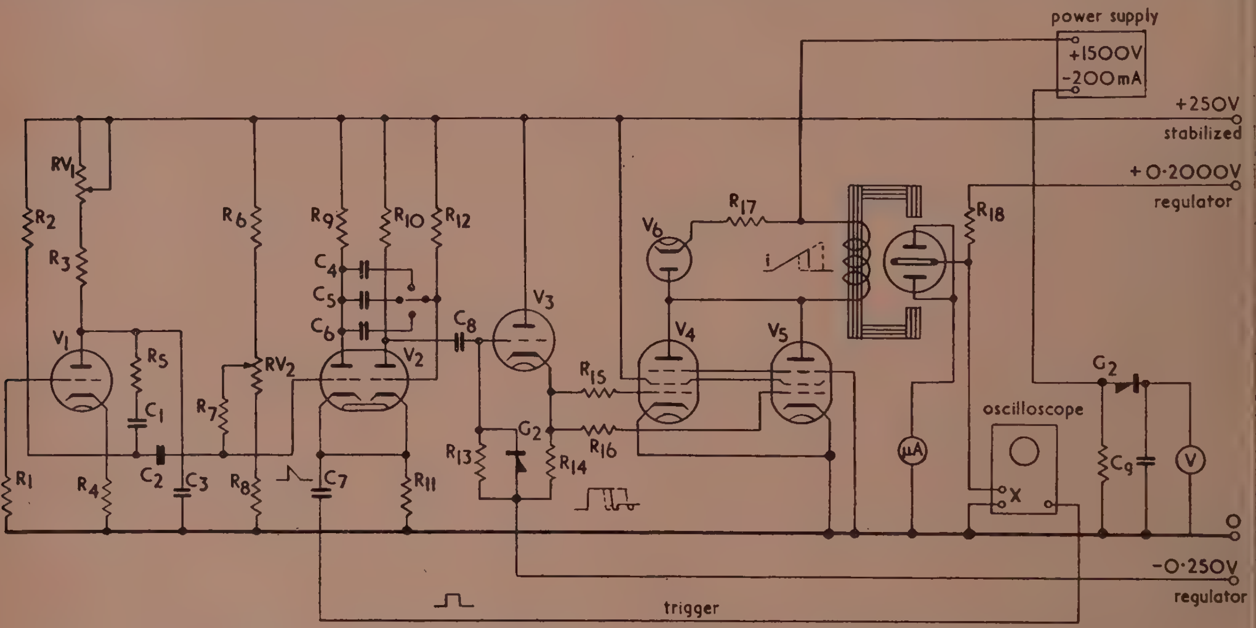


Fig. 1. Circuit diagram of oscillograms showing the dependence of the discharge current on the strength of the magnetic field

R_1 = 50 kΩ
R_2 = 75 kΩ
R_3 = 150 kΩ
R_4 = 1 kΩ
R_5 = 1 kΩ
R_6 = 500 kΩ
R_7 = 500 kΩ
R_8 = 68 kΩ
R_9 = 20 kΩ

R_{10} = 10 kΩ
R_{11} = 10 kΩ
R_{12} = 2 MΩ
R_{13} = 5 MΩ
R_{14} = 20 kΩ
R_{15} = 1 kΩ
R_{16} = 1 kΩ
R_{17} = 5 kΩ
R_{18} = 1–2 MΩ

RV_1 = 2 MΩ
RV_2 = 100 kΩ

C_1 = 0·25 μF
C_2 = 0·01 μF
C_3 = 1200 pF
C_4 = 0·5 μF
C_5 = 0·1 μF
C_6 = 0·02 μF

C_7 = 0·01 μF
C_8 = 0·1 μF
C_9 = 4 μF

G_1 = Philips germanium diode type OA 50
G_2 = Philips germanium diode type OA 50

V_1 = Philips EC 50
V_2 = R.C.A. 6SN7
V_3 = R.C.A. ½ 6SN7
V_4 = Telefunken RL12P35
V_5 = Telefunken RL12P35
V_6 = Telefunken LG2

V = vacuum tube voltmeter

The circuit diagram is shown in Fig. 1. The oscilloscope and the rise of the magnetic field were triggered by a thyratron pulse generator. Its frequency could be varied between 2 and 25 c/s by means of a variable anode resistor. These pulses, of an amplitude of about 150 V, triggered the cathode-coupled univibrator. Positive gating pulses of a variable length were taken from the anode of a univibrator through a cathode follower to the switching stage. This stage consisted of two powerful pentodes with the electromagnet as an anode load. Since the inductivity of the electromagnet was very high (about 250 H) the rise of the current w practically linear (see Fig. 2).

The final current through the electromagnet, and therefo the maximum field strength in the gauge, could be vari simply by the use of gating pulses of different length. Coar variation of the duration of the gating pulses was obtain by changing the condenser C_{4-6}, and fine variation varying the bias of the univibrator.

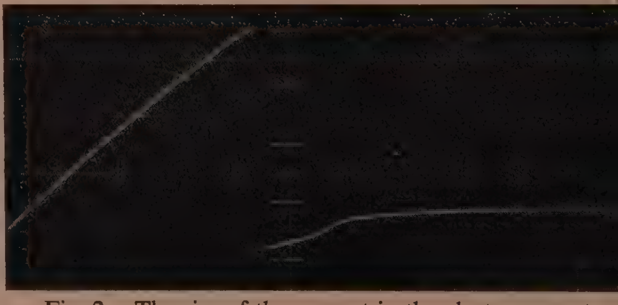


Fig. 2. The rise of the current in the electromagnet

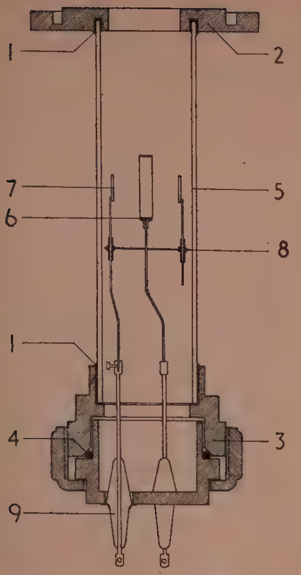


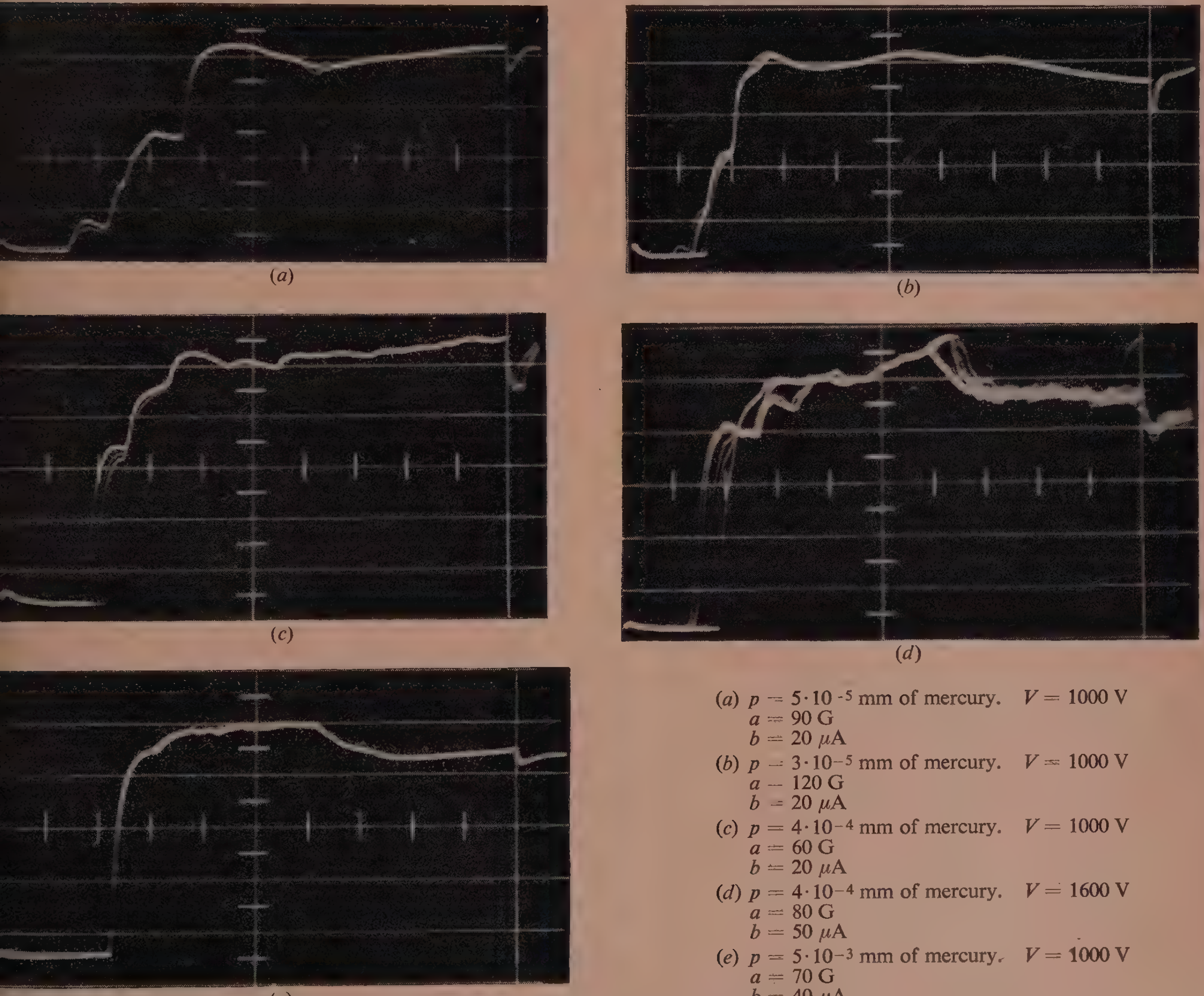
Fig. 3. Gauge system

(1) Araldite.
(2) steel flange.
(3) screwed union.
(4) sealing ring.
(5) glass envelope.
(6) anode ring.
(7) cathode plate.
(8) mica sheet.
(9) glass lead-in.

To determine the maximum field strength, the electromagnet was calibrated against direct current with a fluxmeter. The current at the end of each pulse was measured with a peak voltage meter connected to a resistance in series with the electromagnet. That resistance was adjusted so that a voltage of 10 V across it corresponded to a field of 1000 G between the poles of the electromagnet. Thus the maximum field strength was obtained simply with an accuracy of a few per cent, by multiplying the measured peak voltage by one hundred.

The oscilloscope time-base was triggered simultaneously with the univibrator. The X-deflexion was therefore proportional to the magnetic field. The voltage produced by the current through the Penning gauge across a resistance in series was applied to the Y-plates. Thus the operation of the gauge at different strengths of the magnetic field was evident. The gauge system used for these investigations is shown in Fig. 3.

As it is more convenient to measure the pressure at low values of the anode voltage and of the magnetic field, only values below 2000 V and 1000 G were used in these investi-


(a) (b) (c) (d) (e)

(a) $p = 5 \cdot 10^{-5}$ mm of mercury. $V = 1000$ V
$a = 90$ G
$b = 20$ μA
(b) $p = 3 \cdot 10^{-5}$ mm of mercury. $V = 1000$ V
$a = 120$ G
$b = 20$ μA
(c) $p = 4 \cdot 10^{-4}$ mm of mercury. $V = 1000$ V
$a = 60$ G
$b = 20$ μA
(d) $p = 4 \cdot 10^{-4}$ mm of mercury. $V = 1600$ V
$a = 80$ G
$b = 50$ μA
(e) $p = 5 \cdot 10^{-3}$ mm of mercury. $V = 1000$ V
$a = 70$ G
$b = 40$ μA

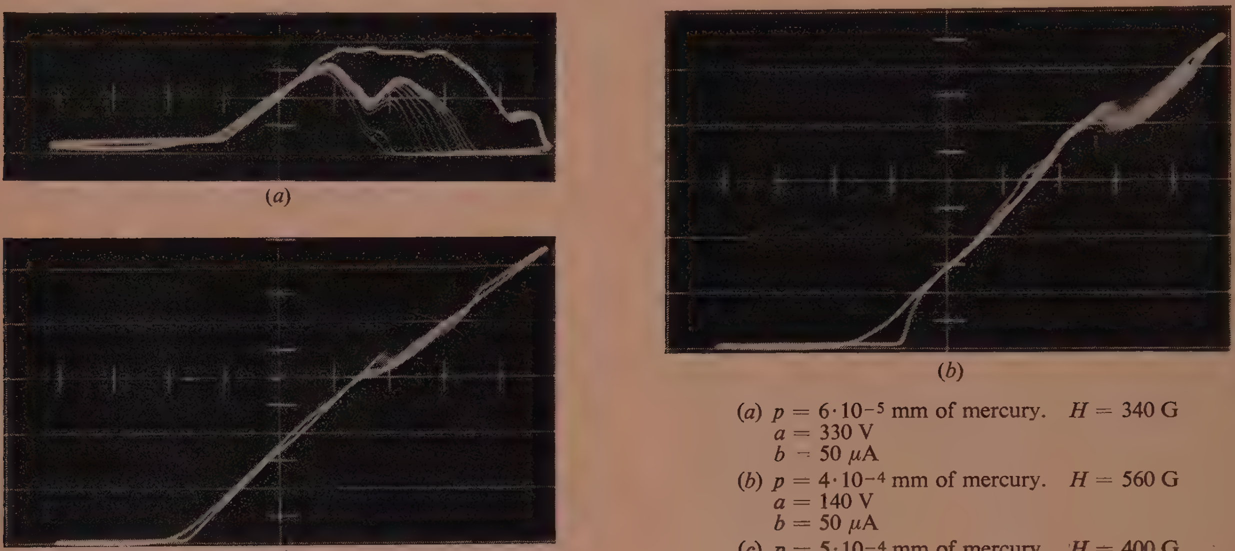
Fig. 4. Oscillograms $I = f(H)$

On all oscillograms a refers to one division of the horizontal axis, and b to one division of the vertical axis; p refers to pressure in the gauge.

gations. The performance of the Penning gauge was investigated under various working conditions at pressures between 10^{-2} and 10^{-5} mm of mercury. The pressures were measured by a McLeod gauge. The best working characteristics of the Penning gauge are those which give stable pressure reading in the whole pressure range. It was found that these conditions were fulfilled whenever the working characteristics were taken on the flat parts of the oscillograms, and that all parts with peaked maxima, oscillations or doubled lines gave inconsistent readings.

for all pressures between 10^{-2} and 10^{-5} mm of mercury in the above mentioned manner. The irregularity arising at higher values of anode voltage can be clearly seen [Fig. 4(*d*)].

Fig. 5 represents some curves giving the variation of the discharge current against the anode voltage(5) for several strengths of the magnetic field, taken with the same gauge system. Fig. 5 (*a*, *b*) illustrate the irregularities in the case of too low and too strong magnetic fields. It can be seen that the operating conditions obtained from these and previous curves agree.


(*a*)

(*b*)

(*c*)

(*a*) $p = 6 \cdot 10^{-5}$ mm of mercury. $H = 340$ G
$a = 330$ V
$b = 50\ \mu$A

(*b*) $p = 4 \cdot 10^{-4}$ mm of mercury. $H = 560$ G
$a = 140$ V
$b = 50\ \mu$A

(*c*) $p = 5 \cdot 10^{-4}$ mm of mercury. $H = 400$ G
$a = 220$ V
$b = 50\ \mu$A

Fig. 5. Oscillograms $I = f(V)$

On all oscillograms *a* refers to one division of the horizontal axis, and *b* to one division of the vertical axis; *p* refers to pressure in the gauge.

The photographs of some oscillograms shown in Fig. 4 were taken with an anode ring of molybdenum, 0·6 cm long and 2 cm internal diameter; the two cathode plates of stainless steel, 1 cm in diameter, were 2·5 cm apart. The optimum operating conditions of this gauge in the pressure range 10^{-2}–10^{-5} mm of mercury were found to be at an anode voltage of 1000 V and a magnetic field of 400 G. In Fig. 4 (*a*, *b*, *c*, *e*) it can be seen that those values were determined

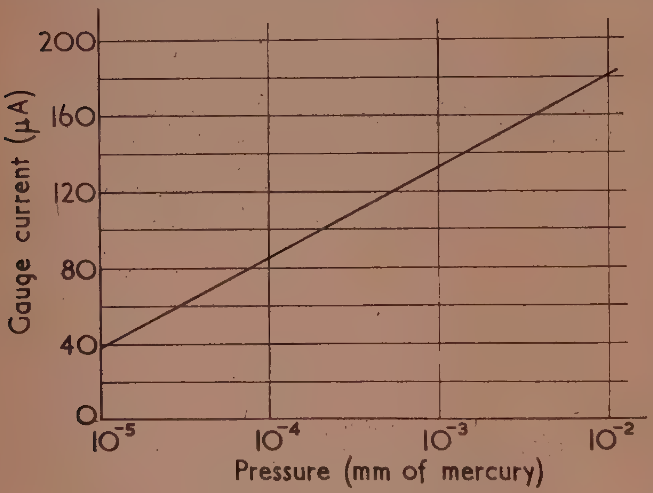


Fig. 6. Pressure calibration curve for air
$V = 1000$ V. $H = 400$ G.

The pressure calibration curve for air of the described gauge system is shown in Fig. 6.

Experiments were carried out with a number of different types of the Penning gauge, using various cathode and anode materials and electrodes of various dimensions. By examining visually the oscillograms of any gauge in the interval 0–1000 G for various anode voltages and for pressures between 10^{-2} and 10^{-5} mm of mercury, the best working conditions could be quickly obtained.

The low values of anode voltage and magnetic field, determined by the method described, were not only convenient to work with, but also gave good results as far as stability and clean-up phenomena(6,7) were concerned.

ACKNOWLEDGEMENTS

The experiments described here were carried out in the Ruder Bošković Institute and the Institute of Physics, Faculty of Science, Zagreb, Yugoslavia. The authors wish to thank Professor M. Paić for his continuous interest in this work.

REFERENCES

(1) Penning, F. M. *Physica*, **4**, p. 71 (1937).
(2) Vermandé, J. J. *Vide*, **7**, p. 1145 (1952).
(3) Chiozzotto, M. *Atti Accad. Sci. Torino*, **81**, p. 82 (1945–47).
(4) Hayaski, C. *Rev. Sci. Instrum.*, **20**, p. 524 (1949).
(5) Varićak, M., and Vošicki, B. *Glasnik Mat.-Fiz.-Astr.*, Ser. II, **10**, p. 1 (1955).
(6) Phillips, K. *J. Sci. Instrum.*, **31**, p. 110 (1954).
(7) Leck, J. H. *J. Sci. Instrum.*, **30**, p. 271 (1953).

A sensitive manometer for rapid chemical reactions

By Sir Eric Rideal, F.R.S., and A. J. B. Robertson, Ph.D., Department of Chemistry, King's College, London, W.C.2

[*Paper first received* 6 *April, and in final form* 21 *June*, 1955]

A manometer is described for the pressure range 1 to 10^{-4} mm of mercury with a response time of 10^{-4} s. The pressure change deflects a thin stainless steel diaphragm which forms the moving plate of an electrical condenser. The capacity changes are converted to voltage changes and recorded on a cathode-ray tube.

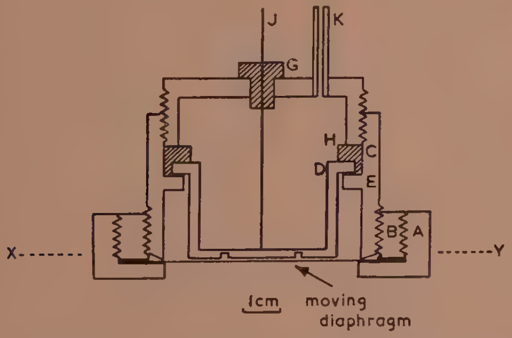
Melville(1) has remarked on the lack of sensitivity and speed of response of manometric methods for gas-phase reactions, and mentioned a goal of sensitivity to 10^{-5} mm of mercury in a time of 10^{-3} s. During some investigations(2,3) of rapid transient phenomena a manometer was constructed for the pressure range 1 to 10^{-4} mm of mercury with a response time of 10^{-4} s. It is probable that the sensitivity mentioned by Melville could be attained by improvements of this manometer. An outline of the apparatus is given below.

GENERAL PRINCIPLES

The pressure deflected the moving plate of an electrical condenser, which formed part of a tuned circuit. Radio-frequency oscillations fed into this circuit were modulated by the changes in pressure. The modulated output was amplified by one, two or three stages, depending on the sensitivity required. The radio-frequency oscillations passed to a detector stage, the output of which was amplified and applied to the deflecting plates of a cathode-ray tube. The apparatus responded to a static pressure. The necessary stability of operation and amplification was achieved by various devices.

THE PRESSURE RECORDING CONDENSER

The moving plate of the condenser consisted of a stainless steel diaphragm 0·01 cm thick and 6 cm diameter, fabricated from hard cold-rolled strip and polished to a bright finish on both sides. An elevation of the condenser unit is shown in the figure, in which the fixed brass plate, forming the other element of the condenser, is along the line *XY*. The figure shows two of the channels which, with holes, were cut in he fixed plate to diminish the resistance of the air gap, as ndicated by Crandall.(4) Clamping rings *A* and *B* held the diaphragm in position, and the tension on it could be adjusted by rotating the cylinder *C*. The part *D* of the fixed plate rested on the shoulder *E* of this cylinder, and was insulated from it by a mica washer. The Perspex block *H* acted as a centralizing ring. Another Perspex block *G* electrically insulated the wire *J* to the fixed plate. The condenser could be evacuated through *K*, so that measurements of pressure change were possible at any total pressure below atmospheric. To adjust the width of the air gap between the two condenser plates, the unit was assembled without the steel membrane and with no mica washer between *D* and *E*. The fixed plate and the ends of the cylinders *C* and *B* were then ground flat and polished. Then, on again assembling with the steel diaphragm and mica washer in position, a gap between the fixed and moving plates was obtained equal to the thickness of the mica washer. A gap of $2{\cdot}5 \times 10^{-3}$ cm was used.



Elevation of the pressure-recording condenser

ELECTRONIC CIRCUITS

Radio-frequency oscillations were obtained from a crystal-controlled oscillator of frequency 3·505 Mc/s. They were passed through a frequency doubler and a limiter pentode with a variable output determined by its screen voltage, which could be set to any one of twelve values with a Yaxley switch. This gave much greater stability than an ordinary variable potentiometer. The radio-frequency oscillations were injected into the tuned circuit, containing the pressure recording condenser, a variable condenser for adjustment, and a high Q coil. This part, except for the pressure-recording condenser, was built inside a double-walled vessel for thermostatic control by water circulation. The working point was on the side of the resonance curve at a height of 0·8 of the maximum. The correct working point was found with a diode voltmeter incorporated into the tuned circuit unit, and this adjustment at the same time balanced the final d.c. push-pull stage. Two cathode followers connected the tuned circuit to the five-stage amplifier. The first had a cathode load consisting of a coil and variable condenser in parallel. When this combination was tuned to a higher or lower frequency than the radio frequency the effective Q of the tuned circuit containing the pressure-recording condenser was decreased or increased. Thus the sensitivity was variable in a fine degree. The second cathode follower led to an amplifier containing two class C stages, one class A–B stage, a detecting diode, and a final push-pull stage giving a maximum output of 1000 V peak-to-peak. The first two stages were each coupled to a cathode follower followed by a band pass transformer adjusted to give a flat response within a band width of 150 kc/s. The state of balance was recorded by the difference of the screen currents of the two final valves. An automatic brilliancy control was added to the cathode-ray tube circuits. This gave an output proportional to the rate of deflexion of the cathode-ray beam. A voltage regulated power pack supplied high tension to all the units except the cathode-ray tube. The current for the valve heaters was not regulated. The apparatus could be operated with none, one, or both the class C stages, depending on the sensitivity required.

TIME SCALE

This is a straightforward problem. Three methods used were a single stroke time base, triggered by the event studied, a repeating hard valve time base, and a rotating drum camera. A satisfactory and light drum was made from a laminated plastic material.

LINEARITY AND RESPONSE

The apparatus, operating under typical conditions without the class C amplifiers was calibrated with a static pressure over a range of pressure of 0 to 2·20 mm of mercury. The deflexion of the cathode-ray beam at the highest pressure was 14 cm. The deflexion increased linearly with pressure from 0 to 1·4 mm of mercury at a rate of 1 mm on the screen for $1 \cdot 6 \times 10^{-2}$ mm of mercury pressure. Thus the deviation from linearity at the highest pressure was only 2%, which was, in fact, about the accuracy of measurement of the deflexion.

To test the response the apparatus was operated with both class C amplifiers, and used to register the sound waves from a loudspeaker connected through a transformer to the output of a beat frequency oscillator. Satisfactory response was noted up to nearly 10^4 c/s. This response was found adequate for the majority of the rapid reactions studied, which were found to take not less than an appreciable fraction of a millisecond. The behaviour of the apparatus at higher frequencies was not, therefore, examined. Reactions taking less than a millisecond often set up oscillations in the reaction vessel which were communicated to the pressure-recording condenser and made accurate observations difficult. These oscillations appeared to be largely mechanical. To study definite shock waves, with a velocity exceeding that of sound, caused by very rapid reactions, it was more satisfactory to suspend the pressure-recording condenser in free air on an elastic cord.

Pressure changes of 10^{-4} mm of mercury could be followed with both class C amplifiers in operation.

ACKNOWLEDGEMENT

We thank Mr. N. S. Nichols for the design and construction of the electronic circuits.

REFERENCES

(1) Melville, H. W. *Disc. Faraday Soc.*, **17**, p. 9 (1954).

(2) Rideal, E. K., and Robertson, A. J. B. *Proc. Roy. Soc. A*, **195**, p. 135 (1948).

(3) Rideal, E. K., and Robertson, A. J. B. *Third Symposium on Combustion and Flame and Explosion Phenomena*, p. 536 (Baltimore: Williams and Wilkins Co., 1949).

(4) Crandall, I. B. *Phys. Rev.*, **11**, p. 449 (1918).

A recording water velocity meter

By M. J. Wilkie, B.Sc., A.Inst.P., Hydraulics Research Station, Wallingford, Berks.

[*Paper first received* 6 *October*, 1954, *and in final form* 8 *March*, 1955]

An account is given of an instrument suitable for measuring and recording water velocities from one or two centimetres per second to several metres per second using a miniature propeller-type current meter. Each propeller blade in passing a fixed electrode slightly increases the impedance between this electrode and the supporting frame of the propeller, generating a voltage pulse in the associated circuit. The pulse-rate is measured by an electronic tachometer. The range and accuracy are discussed and polar diagrams presented, showing the effect of different propeller mountings.

This instrument was developed primarily for the measurement of low water velocities, of the order of 2 to 30 cm/s, in hydraulic models. As a matter of interest it was calibrated at higher velocities, up to about 2 m/s, which was the maximum known velocity available. It has been run without damage in a jet of much higher velocity, by extrapolation about 3·5 m/s. A brief description of the measuring head and details of an electronic unit suitable for "spot" readings of velocity have already been published.(1) This present paper describes an electronic unit which gives a continuous record of the water velocity.

GENERAL DESCRIPTION

For work in models, the measuring head consists of a polystyrene rotor with five helical blades, mounted on a stainless steel spindle running in jewel bearings. The swept diameter of the rotor is 1 cm. The rotor is protected by a frame, which is mounted on a stainless steel tube. A gold wire insulated from the tube passes down inside it and finishes

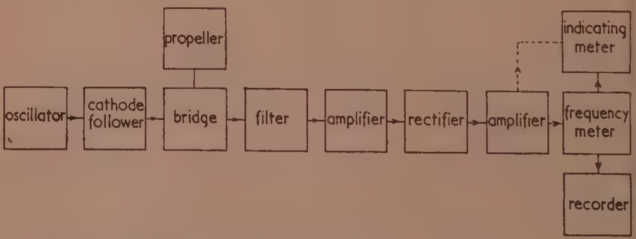


Fig. 1. Block diagram of recording water velocity meter

about 0·1 mm clear of the propeller blades. The measuring head is connected to the electronic unit by coaxial cable.

The resistance between the tip of the central gold wire and the stainless steel tube, when the head is in water, varies slightly as each propeller blade passes the tip. The measuring head and cable form one arm of a Wheatstone bridge network nergized at a high audio-frequency; the bridge is adjusted lmost to balance. The output from the bridge consists of he carrier modulated by pulses, the pulse repetition rate eing that of the blades past the gold probe.

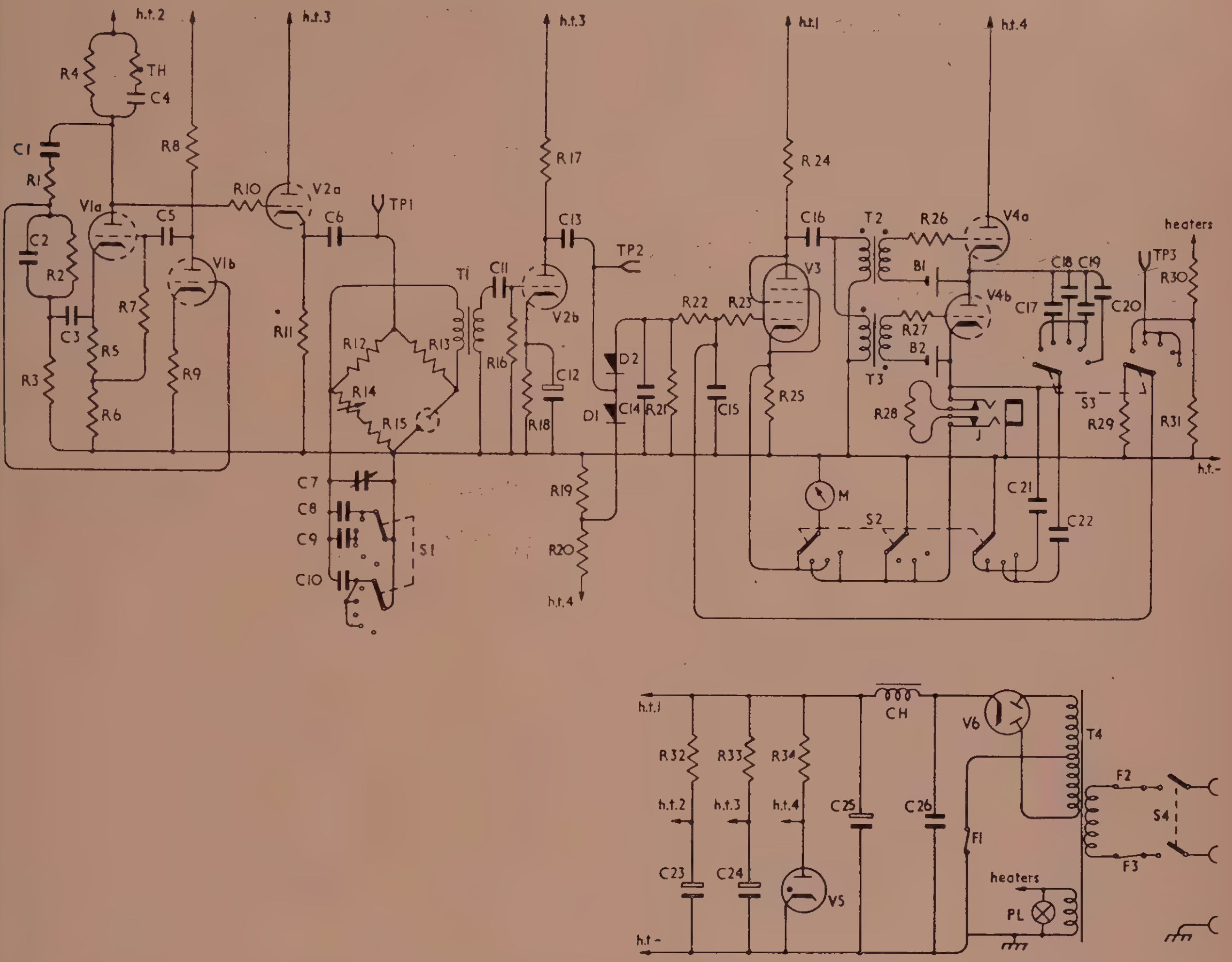

h.t.2
h.t.3
h.t.3
h.t.1
h.t.4
R4
TH
C4
C1
R1
R8
V1a
C5
R10
V2a
C6
TP1
R17
C13
C16
R24
T2
R26
V4a
heaters
C2
R2
V1b
TP2
T1
C11
V3
B1
V4b
C18 C19
TP3
R30
R7
C3
R5
R11
R12
R13
R16
V2b
R22
R23
C17
C20
R27
B2
R3
R9
R14
C12
D2
T3
R6
R15
R18
D1
C14
R21
C15
R25
R28
S3
R29
R31
h.t.-
C7
C8
C9
C10
S1
R19
R20
h.t.4
M
S2
C21
C22
h.t.1
CH
V6
T4
R32
R33
R34
F2
h.t.2
h.t.3
h.t.4
C25
C26
S4
F1
F3
C23
C24
V5
heaters
PL
h.t -

Fig. 2. Circuit diagram of recording water velocity meter

R_1, R_2 = 0·1 MΩ
R_3 = 0·22 MΩ
R_4 = 22 kΩ
R_5 = 470 Ω
R_6 = 3·3 kΩ
R_7 = 0·22 MΩ
R_8 = 22 kΩ
R_9 = 1 kΩ
R_{10} = 390 Ω
R_{11} = 47 kΩ
R_{12}, R_{13} = 47 kΩ, 1%
R_{14} = 50 kΩ, w.w.
R_{15} = 10 kΩ, 1%
R_{16} = 1 MΩ
R_{17} = 0·22 MΩ
R_{18}, R_{19} = 3·3 kΩ
R_{20} = 0·1 MΩ
R_{21} = 1 MΩ

R_{22} = 0·1 MΩ
R_{23}, R_{24} = 22 kΩ
R_{25} = 7 Ω (see text)
R_{26}, R_{27} = 22 kΩ
R_{28} = 3·3 kΩ
R_{29} = 10 kΩ
R_{30} = 4·7 kΩ
R_{31} = 1 kΩ
R_{32}, R_{33} = 10 kΩ
R_{34} = 6·8 kΩ

C_1, C_2 = 100 pF
C_3–C_6 = 0·01 μF
C_7 = 150–700 pF
C_8 = 2000 pF
C_9 = 1000 pF
C_{10} = 470 pF
C_{11} = 100 pF

C_{12} = 1 μF
C_{13}–C_{15} = 0·01 μF
C_{16} = 8 μF paper
C_{17} = 1 μF
C_{18} = 0·25 μF
C_{19} = 0·1 μF
C_{20} = 0·025 μF
C_{21} = 50 μF
C_{22} = 1000 μF
C_{23} = 8 μF
C_{24} = 4 μF
C_{25} = 8 μF
C_{26} = 4 μF

V_1 = CV491
V_2 = CV492
V_3 = CV138
V_4 = CV455

V_5 = CV686
V_6 = CV493

T_1 = 1 : 4
T_2, T_3 = 1 : 1
T_4 = 250 V, 60 mA

F_1 = 100 mA
F_2, F_3 = 2 A

TH = S.T.C. A1522/100
M = 1 mA
B_1, B_2 = 5·2 V Mallory
D_1, D_2 = GEX 35
CH = 50 H, 60 mA
PL = 8 V, 0·15 A
TP_1–TP_3 = test points

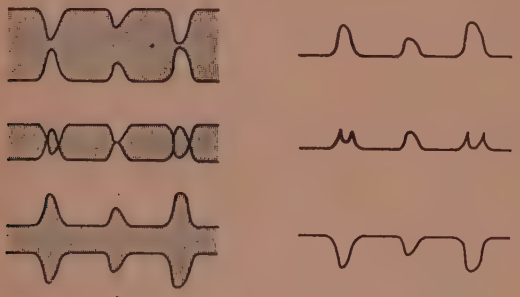
A block diagram of the arrangement is given in Fig. 1. The oscillator operates at about 14 kc/s. The cathode follower s a buffer between oscillator and bridge. The output from the bridge goes through a high-pass filter to reduce stray pick-up from the a.c. mains and is then amplified and rectified, and the carrier frequency filtered out. The resulting pulses are amplified and fed to a frequency meter. Several frequency meters have been tried, all based on the charge and discharge of a capacitor as follows: (*a*) the circuit described later, using series and shunt triodes$^{(2)}$; (*b*) a high-speed relay circuit; (*c*) the "diode pump" in which a small capacitor is repeatedly discharged into a larger one$^{(3)}$; (*d*) an overdriven amplifier and rectifier meter circuit based on a Post Office design.$^{(4)}$ Methods (*a*), (*b*) and (*d*) give a linear relation between pulse rate and meter reading, method (*c*) gives an exponential relation (which may be of value if a wide range is required on one scale). Some of the drawbacks are: method (*a*) requires bias batteries and transformers, method (*b*) requires an expensive relay which will require adjustment at intervals, and in method (*d*) mains frequency ripple produces a reading on low ranges of the meter for zero water velocity.

Method (*a*) was chosen chiefly because of its linear scale and because the author had had previous experience with this type.

DETAILED CIRCUIT

Referring to Fig. 2, the double triode V_1 and its associated components comprise a Wien bridge oscillator, the frequency being controlled by R_1, R_2, C_1 and C_2, and the amplitude being stabilized by the thermistor *TH*. V_{2A} is the buffer cathode follower feeding the bridge circuit. The measuring head impedance consists effectively of the resistance between the electrodes shunted by the cable capacitance, and polarization capacitance, and these are balanced on the bridge by R_{14} and C_{7-10}. The bridge is coupled to V_{2B} by an isolating transformer T_1 and the components C_{11} and R_{16}. The time constant of the combination C_{11} and R_{16} is chosen to pass the carrier with little attenuation but to reduce the amplitude of mains frequency pick-up. The choice of a suitable value is complicated by the "Miller" input capacitance of V_{2B}. The amplified signal from V_{2B} is rectified by the voltage doubling rectifiers D_1 and D_2 and the carrier frequency filtered out by R_{22} and C_{15}. The signal is then amplified by V_3, the bias for which is obtained from the rectified signal. The resistance of R_{25} (a shunt for the meter *M*) is too low to produce appreciable bias. When the bridge is considerably unbalanced the bias is sufficient to cut off V_3 and it is then impossible to tell in which direction to adjust R_{14} and C_7 for balance. When switch S_3 is in the position shown, however, it reduces the bias applied to V_3 to about one-tenth of its value, so that the valve is no longer cut off and the bridge can be roughly balanced by adjusting for maximum reading on meter *M*. Fine balance is obtained after switching S_3 to the third position, when the full bias is applied to V_3.

Fig. 3 shows how different settings of the bridge balance controls affect the rectified output. When the bridge is nearly balanced, double pulses may be produced which give a false reading. To avoid this, after bringing the bridge as near to balance as possible, it is unbalanced by R_{14} so that only single pulses are obtained. The bias produced by this necessary unbalance would cut off V_3 if D_1 were connected directly to negative high tension. By applying a slight positive voltage by means of R_{19} and R_{20}, V_3 is operated at a suitable bias.



Signal from bridge (*a*)

Signal from rectifier (*b*)

Fig. 3. Effect of bridge balance adjustment on observed pulse rate

The frequency meter to which the signal is next applied consists of two triodes V_{4A} and V_{4B} connected in series, with a capacitor (C_{17} to C_{20} according to range) in shunt across one of them. Both valves are biased beyond cut off and the transformers T_2 and T_3 are connected so that the signals on the grids are in antiphase. A sinusoidal or pulsed signal causes the valves to conduct alternately, charging and discharging the capacitor once per cycle. The charging voltage h.t.$_4$ is stabilized by V_5, so that, providing the signal voltage is sufficient to cause the capacitor to charge and discharge completely, the mean current through the circuit is proportional to the frequency or pulse rate. This current can be indicated on *M* by switchng S_2 to the second or fourth position. The condensers C_{17}–C_{20} have been chosen to give ranges of 0–10, 0–40, 0–100 and 0–400 pulses/s approximately. Position 2 on S_3 supplies a small mains frequency voltage to the grid of V_3 and selects the 0–100 range. This gives a rapid check on the frequency meter.

A 1 mA pen recorder can be plugged into the circuit to record the pulse rate; R_{28}, which is approximately the same value as the recorder resistance, being cut out so that the calibration is unchanged. C_{21} and C_{22} provide two degrees of smoothing of the output signal, the time constants being 0·17 s and 3·3 s, respectively. Switch S_2 selects one of four alternative modes of operation:

(1) *M* observing bridge balance. Recorder observing pulse rate. Short time constant.

(2) Recorder and *M* observing pulse rate. Short time constant.

(3) As mode (1) but long time constant.

(4) As mode (2) but long time constant.

It is thus possible to check the bridge balance, which wanders slightly, while recording. The longer time constant is necessary at low pulse rates and is also useful if the average value of a fluctuating velocity is required.

Test sockets are provided at the bridge input, rectifier input and pulse amplifier input, so that the operation of the unit may be checked with an oscilloscope. In addition the instrument can be calibrated in terms of frequency by feeding a signal from an audio oscillator into TP_3.

CALIBRATION

The measuring heads are calibrated over the range 0–50 cm/s by drawing them at known speeds through still water in a circular flume. The Dekatron unit described in Ref. (1) is used to determine the pulse rate. A typical calibration curve of pulse rate against speed is given by the heavy line in Fig. 4. The electronic units are calibrated in terms of frequency, typical results giving the fainter lines in Fig. 4. The dotted line shows the method of determining the water velocity from the meter reading. It is, of course, possible to calibrate the whole instrument directly in terms of water velocity, without the aid of the Dekatron unit and audio oscillator, but in that case each measuring head is tied to its own electronic unit.

Fig. 5 shows the results of a calibration up to higher velocities, the measuring head being held stationary in moving ater. The velocity of the latter was measured by Pitot tube nd manometer. The recording velocity meter was used for is experiment, the meter readings being converted to ulses per second before plotting.

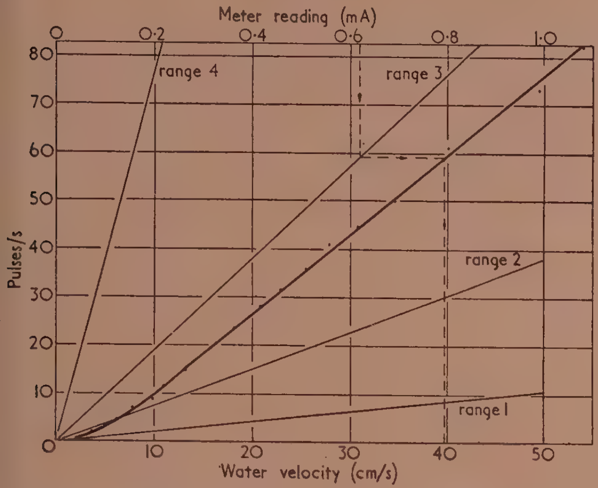


Fig. 4. Calibration curves of measuring head No. 5 and electronic unit No. 2

Example: meter reading 0·62 mA range 3; velocity 39·7 cm/s.

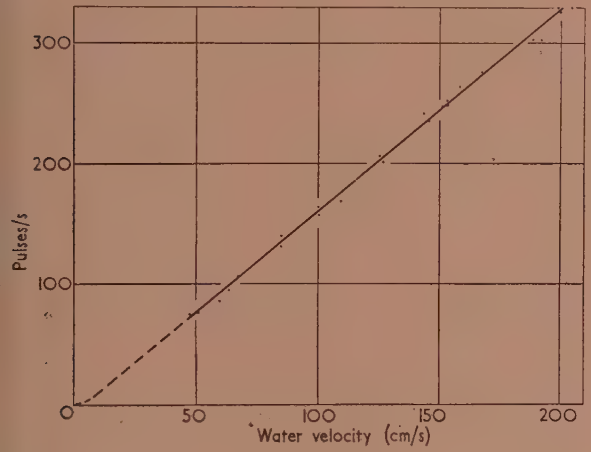


Fig. 5. Calibration over wide velocity range

- - - - calibration curve from circular flume.

——— calibration against Pitot tube.

Fig. 6 shows one quadrant of the horizontal polar diagram or the measuring head at three different speeds. Fig. 7 is similar diagram for a modified head in which the rotor was ounted inside a short Perspex tube. The dotted semicircle each case shows the response expected if the head measured e component of velocity along its axis. In the first case the esponse is less than predicted, in the second greater. Preumably a close approximation to a cosine law could be btained by varying the dimensions of the Perspex tube. hree such units mounted at right angles would give complete formation on velocity and direction.

The rate of response of the propeller to varying flow rates is very good, owing to its low inertia. To demonstrate this the measuring head was held in a stream of water flowing at about 30 cm/s, the rotor being prevented from moving by a piece of wire. A high-speed pen recorder was connected to record pulses at the grid of V_3. The rotor was released by suddenly withdrawing the wire. The interval between the first two pulses recorded was not measurably greater than between subsequent pulses, so the rotor must have reached full-speed in less than $\frac{1}{5}$ revolution, 0·03 s at this speed.

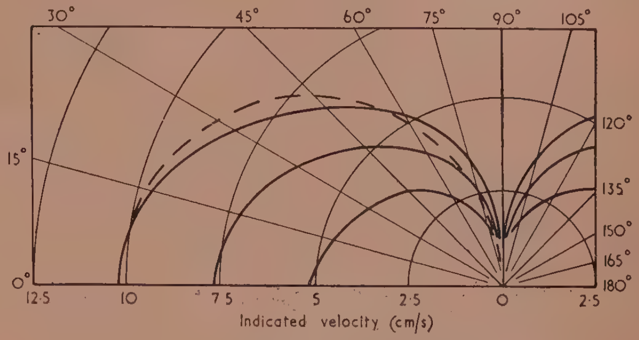


Fig. 6. Polar diagram for frame mounted rotor

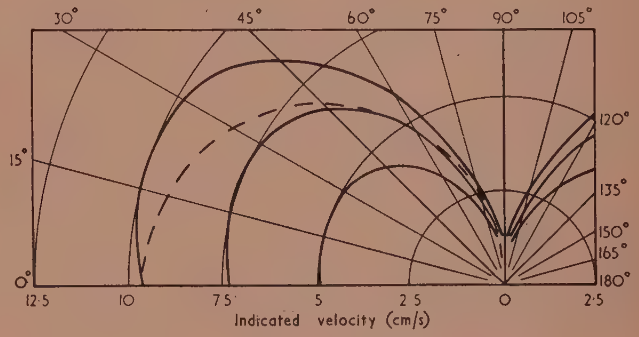


Fig. 7. Polar diagram for tubular mounted rotor

ACKNOWLEDGEMENTS

The measuring heads were developed by Mr. H. R. Dedow. The project was part of the research programme of the Hydraulics Research Station, and this account is published by permission of the Director.

REFERENCES

(1) Dedow, H. R., and King, R. F. *Engineering* [*London*], **178**, pp. 396–398 (1954).

(2) Guarnaschelli and Vecchiacchi. *Proc. Inst. Radio Engrs*, **19**, p. 659 (1931).

(3) Ball, R. M. *Rev. Sci. Instrum.*, **24**, p. 323 (1953).

(4) *Post Off. Radio Rep.*, No. 1168 (1944).

A simplified form of microwave interferometer for speed measurements

By G. W. G. Court, B.Sc., A.M.I.E.E., A.Inst.P.,* Department of Scientific and Industrial Research, Dominion Physical Laboratory, Lower Hutt, New Zealand

[*Paper first received* 10 *November*, 1954, *and in final form* 4 *March*, 1955]

A simplified form of radio-frequency interferometer is described. It is particularly suitable for microwave applications, in particular, the determination of the Doppler frequency shift due to the motion of a target. One aerial is used and a hybrid junction separates transmitting and receiving paths, thus enabling a single oscillator to provide both transmitter and local oscillator power.

A brief outline is given of a developed equipment used for the measurement of the speed of road vehicles. Possible uses of the instrument in measurement of distance have been examined and its use in the study of microwave reflexions from the sea surface is being investigated.

A number of applications of radio-frequency techniques to interferometry systems have been made, e.g. the Michelson interferometer which has been used by Culshaw(1) and others, for both measurements of wavelength and dielectric constants. The system described in this paper was originally tested in June, 1952, in New Zealand as a velocity measuring system, using a frequency of 10 000 Mc/s and is similar in form to a method used by Froome for the measurement of wavelength in the 25 000 Mc/s region.(2) Froome(2) has used a hybrid junction to provide a power splitter as in the Michelson interferometer and uses the power reflected by a short circuit in one arm for comparison with power returned from a reflector on the other arm of the interferometer. In the system described in this paper the power into one arm is absorbed and only leakage power to the detector arm is used for interference with reflected signals in the other arm.

The determination of the velocity of moving sources of radiated energy by measurement of the resultant shift of frequency of the radiation, as seen by a fixed receiving system is well known and has been applied in many fields. In the radio and radar fields various systems of varying degrees of complexity have been devised to determine the Doppler frequency shift due to the reflexion of radio waves from a moving target.(3) The system to be described is simple in form and has proved very satisfactory in its practical application.

Consider a continuously oscillating (C.W.) source radiating energy through a feeder system to an aerial. Now let a fixed target reflect part of this energy back to the aerial. The system becomes mismatched and a standing wave will be set up in the feeder. This can be detected by suitable devices, e.g. a probe moved along the feeder system with the energy picked up in it actuating a meter. If the target is moved, then the position of the standing wave will move and can be detected as so doing by the probe. To detect small or distant targets and their movements in the radiated beam of the aerial requires this probe detecting system to be sensitive. As it is situated in the relatively high power field of the transmitted energy, practical difficulties arise, since a device sufficiently sensitive to response to the low level of received energy is likely to be damaged by the high level of the transmitted power.

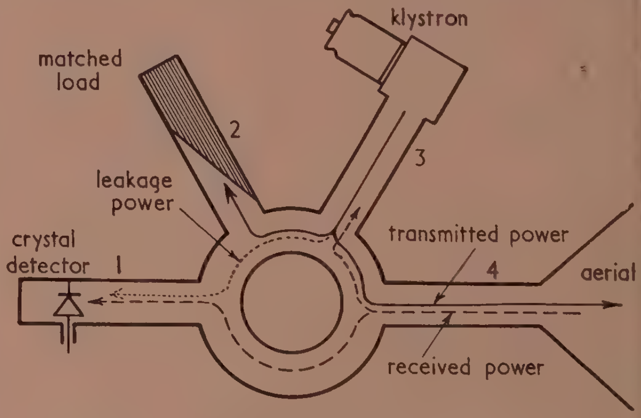
A typical method of overcoming this difficulty is to use a system of separate transmitting and receiving aerials. In this way a very small amount of leakage of transmitting power into the receiver channels can be accomplished and a sensitive detection system employed. A number of so-called C.W. radar systems have been made on this principle and used for the detection and measurement of the radial velocity of moving targets.

In the system to be described a waveguide hybrid junction has been used to separate the transmitting and receiving paths and also allow a small amount of leakage to the transmitted power to the detecting element for comparison with the received power.

USE OF HYBRID JUNCTION

In the microwave radio field typical examples of hybrid junctions are the magic T and the hybrid ring junction or "rat race."

The assembly of radio-frequency components interconnected by a hybrid ring is shown in the figure. The klystron oscillator on arm 3 supplies microwave energy which divides equally between arms 2 and 4. Arm 2 is terminated in a matched load which absorbs the energy entering it, the other half, passing into arm 4, is radiated from an aerial.



Hybrid ring assembly

Arm 1 is terminated by a silicon crystal detector, and in a theoretically perfect hybrid ring no energy enters this arm. In practice, however, arms 3 and 1 are not completely isolated, but the attenuation factor between them is of the order of 30dB or more. Thus there is a small leakage of power directly from the klystron to the crystal, but insufficient to damage it.

---

* Now at Civil Aviation Administration Air Department, Wellington.

The amount of power entering arm 1 can be adjusted by uitably mismatching arm 2, but in practice no such adjustnent has been found necessary.

From a target in the aerial beam, power is reflected back nto arm 4 and it then divides equally between the klystron rm and the detector arm. The level is, in general, very mall compared with the transmitter power, and the effect on he klystron performance is negligible. The leakage of eceived power to arm 2 is also negligible.

In this way the requirements of a system for detecting the oltage standing wave due to a reflecting target is achieved. The detecting crystal receives some small part of the transnitted power and half of the received power. A suitable neter attached to the crystal detector will show an output orresponding to the relative phase of the transmitted and eceived signal at the crystal position, as is the case with the probe in the feeder in the arrangement described earlier. In his initial arrangement a movement of the target provides a novement of the standing wave set up in the feeder and this novement will be shown by a variation of the meter reading. Similarly in this case a change in the position of the target vill alter the phase of the received signal at the crystal and ince the transmitted signal phase is unchanged the resultant change in output from the crystal will be an indication of the arget movement.

COHERENT DETECTION

It will be seen that, if the oscillator frequency is stable and the target is stationary, this system will satisfy the requirements for coherent detection. In practice, however, an oscillator at microwave frequencies is not stable, but for targets at short ranges the time of travel to and from the target is short enough to ensure that no significant change of oscillator frequency takes place in that period and the system is coherent.

For a moving target the system is better named as a homodyne detector, the resultant instantaneous output being proportional to cos ϕ where ϕ is the phase difference between transmitted and received signals at the point of detection.

VELOCITY MEASUREMENT

It can be seen that if the target range is changed by $\lambda/2$ the standing wave pattern will move a complete cycle, i.e. the detector output will go through a complete cycle. The output is proportional to cos ϕ where ϕ is the phase differences as above. If the target is moved a distance $\lambda/2$, the total path change is λ and the consequent change in ϕ is 2π.

For a target moving with a velocity v, the output for the detector is a sinusoid of frequency

$$2v/\lambda \text{ or } 2vf/c \qquad (1)$$

where f is the radio-frequency transmitted, and c is the velocity of electromagnetic waves.

The arrangement may equally well be considered as a superheterodyne receiver of zero intermediate frequency to give the same result. The leakage power from the transmitter channel provides the local oscillator signal which mixes with the received signals in the crystal detector.

Now applying the Doppler principle to a moving target, the received frequency is given by

$$f(1 \pm 2v/c) \qquad (2)$$

and the resultant output from the superheterodyne is the frequency difference

$$f\,.\,2v/c \qquad (3)$$

and is a measure of the target velocity as before.

PRACTICAL APPLICATIONS

Velocity measurements. The practical convenience of the system has been demonstrated in various laboratory tests in which a radio-frequency of 10 000 Mc/s has been used. The unit is small enough to be readily handled and positioned, and with it, such tests as checking the velocity of falling bodies have been carried out. The sensitivity of detection of moving objects is such that, using a paraboloid aerial of about 18 in. diameter, small birds can be observed in the aerial beam at ranges up to approximately fifty yards, and small metal objects of $\frac{1}{4}$ in. diameter produce signals well in excess of noise at the maximum distance of fifty feet available in the laboratory. The possibilities of increased sensitivity by integration methods following the homodyne detector have not been exploited,$^{(4)}$ but it is to be expected that the use of a narrow band audio-frequency filter for this purpose would give considerably increased sensitivity if a particular application required it. As an example the system could be applied to measurements of velocities of rifle bullets, shells, etc., and the use of a series of filters covering the velocity ranges encountered would be possible. Equally well the sensitivity can be increased by the use of a larger aerial with the consequent reduction in beam width; an increase in the radio-frequency employed would produce a similar result.

A practical development of the system has been carried out to provide an equipment which determines the speed of road vehicles.$^{(5)}$ This equipment operates at a radio frequency of 10 000 Mc/s and uses an 18 in. diameter paraboloid aerial, and practical tests have been very satisfactory. As a result commercial manufacture of a number of such equipments is being carried out for the New Zealand Transport Department.

The virtues of the system as opposed to earlier schemes for such speed measurements are apparent in this development, there being a considerable reduction in complexity of the equipment, weight, power requirements and maintenance requirements, when compared with previous equipments using two aerials, and the normal superheterodyne receiver system.

Briefly described the equipment consists of three units, the aerial head, the amplifier and frequency measuring circuit and a vibrator unit power supply operated from a 12 V battery. The aerial head contains the radio-frequency system which has been described, and the detector output from it, which is a low level sinusoidal waveform, is amplified by a three-stage audio-frequency amplifier. The output of the amplifier is then converted to a pulse waveform and used to initiate a frequency measuring circuit in which the mean current of a switched valve is proportional to the frequency of switching. This current is displayed by a meter which is calibrated in miles per hour. In all a total of seven valves are used in the electronic circuits, which fact indicates the simplicity of the equipment.

It is found that the equipment will readily indicate speeds of medium size cars to ranges of 200–300 yards. Audible Doppler frequencies are obtained from vehicles at ranges appreciably in excess of this.

Distance measurement. Froome$^{(2)}$ has given a detailed account of the errors arising and difficulties involved in the use of a radio-frequency interferometer for the measurement of length. Some initial tests using this instrument in conjunction with a switched gaseous discharge as a reflector$^{(6)}$ have amply demonstrated the difficulties. Although it has been possible under limited conditions to determine the reflector positions, for minima indications, to about 0·001 in., it is apparent that the complication and difficulties involved in carrying out a length determination completely overshadow any simplifications in equipment provided by the instrument itself.

Reflexion from the sea surface. A further application of the system will be in a project to investigate the Doppler frequency spectrum of microwaves reflected from the sea surface. The advantages of the system in providing simple practical units on wavelengths of 3, 10 and 30 cm are apparent in the equipment at present being constructed.

ACKNOWLEDGEMENTS

This paper is published with the permission of the Secretary of the Department of Scientific and Industrial Research, New Zealand.

REFERENCES

(1) Culshaw, W. *Proc. Phys. Soc.* [*London*] *B*, **63**, p. 939 (1950).
(2) Froome, K. D. *Proc. Roy. Soc. A*, **213**, p. 123 (1952).
(3) Barlow, E. J. *Proc. Inst. Radio Engrs*, **37**, p. 340 (1949).
(4) Smith, R. A. *Proc. Instn Elect. Engrs*, **98**, p. 43 (1951).
(5) New Zealand Patent Application No. 109285 (1953).
(6) Court, G. W. G. *Nature* [*London*], **174**, p. 307 (1954).

A stress-strain machine for testing single crystals in alternating tension and compression

By M. S. Paterson, B.E., Ph.D., Department of Geophysics, The Australian National University, Canberra, Australia

[*Paper received* 26 *April*, 1955]

A testing machine for single crystals is described, by means of which the stress-strain behaviour in cycles of alternating tension and compression can be measured; special precautions are taken to eliminate external bending or torsion of the specimen. The load and extension gauges are of the roller and mirror type for high sensitivity. The difficulty of gripping a single crystal firmly without damaging it is overcome by using a chuck in the form of a mould, into which the crystal is cast with solder. Examples of the performance of the machine are given.

In studying the mechanism of the fatigue of materials, it is desirable to measure the stress-strain behaviour of single crystals during successive cycles of alternating strain. Such measurements cannot readily be made in a conventional high-speed fatigue machine because of the difficulty of measuring accurately the stress and strain. On the other hand, a conventional universal testing machine is not suitable for deforming single crystals successively in tension and compression because of irregular behaviour when the load passes through zero. In either case, the problem of gripping a soft single crystal firmly, without distorting it, must be solved. The machine described in this paper was designed to overcome these difficulties and so to assist in studies of the properties of materials in reversed deformation, such as strain hardening, Bauschinger effect, etc., which might increase our understanding of the mechanism of fatigue and extend our general knowledge of plastic deformation.

A testing machine for alternating shear has been described by Held.$^{(1)}$ However, the present machine applies tension and compression in order to achieve uniform stress in the specimen. It was designed to meet the following requirements:

(1) A maximum load capacity of 100 kg, so that single crystals of most ductile materials with diameters up to several millimeters can be deformed plastically.

(2) The achievement, as far as possible, of pure tensile or compressive straining of the specimen.

(3) The measurement of stress-strain curves on a given specimen alternately in tension and compression, without incurring error due to hysteresis or backlash in the measuring devices when the load changes sign.

(4) The observation of the surface of the crystal during straining; this permits correlation of the stress-strain behaviour with the appearance and distribution of slip lines and other strain markings.

GENERAL DESCRIPTION

The principal features of the machine are shown in Figs. 1 and 2. Its framework consists of three stiff plates *E*, *E′*, *F* and four thick rods *P*, carried on a heavy base.

The upper specimen chuck *A* is made as an extension of the stiff rod *C* which is attached to the centres of the two widely spaced, parallel spring plates *D*, *D′*. The ends of the spring plates are bolted firmly to the stiffened plates *E*, *E′* so that no slippage occurs. Thus any cyclic load applied to the specimen *S* will cause a deflexion of the spring plates that is free from friction or backlash and is therefore a reliable measure of the load. The spring plates are made of high strength steel (for low hysteresis), with dimensions such that the vertical deflexion is readily measurable but still very nearly proportional to the load, while any lateral deflexion due to non-axial loads arising from eccentricity of the specimen will be negligible.

The lower chuck *B* is fixed by means of the *U*-shaped bracket *I* to the lower end of the stiff yoke *H*, which is made of two channel sections joined at the top by a plate carrying a nut *K*; this can be moved up or down by the driving screw *Q*, thereby applying load to the specimen *S*. The nut *K* is split and its two halves are held apart by a spring which is compressed to a slightly greater extent than would correspond to the maximum load to be used in a test. The backlash in he drive is thereby greatly reduced and any appreciable nterruption in the straining of the specimen when the load asses through zero is avoided. The chuck B is constrained o move in a straight line by the two widely spaced, parallel eryllium copper sheets J, J' which are attached at their orners to the rods P of the frame and at their centres to the nds of the yoke and lower chuck assembly. This permits ertical displacements of the lower chuck of several millineters, while preventing any significant lateral deflexion due o non-axial loads. The position of the lower chuck may be et to accommodate specimens of different lengths by attachng the sheets J, J' to the rods P at suitable heights. Thus both hucks are constrained to move in straight lines which must e parallel if the flexible components D, D', J, J' are initially ll parallel. Then, if the chucks hold the specimen parallel o this direction of motion, the specimen must be subjected o purely tensile or compressive straining.

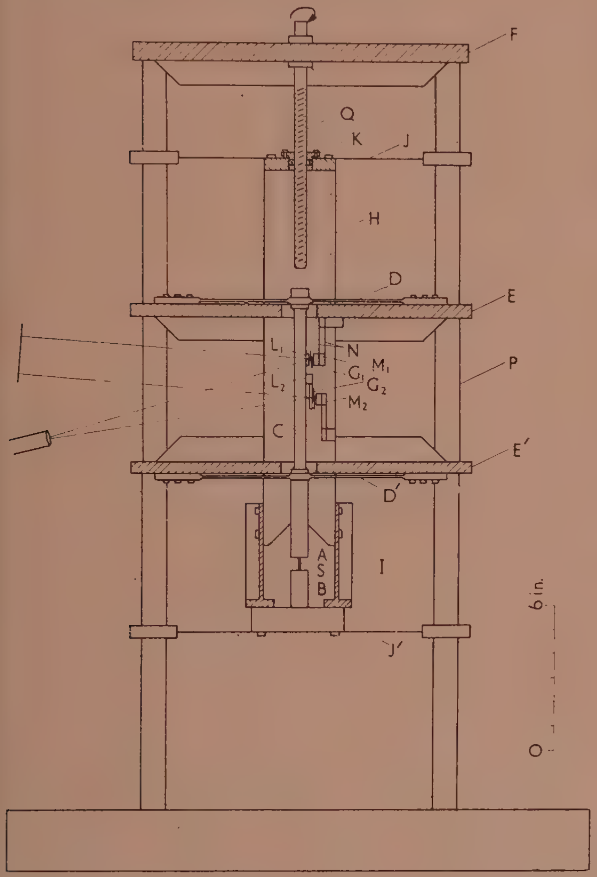


Fig. 1. General arrangement of stress-strain machine

The screw Q may be driven by a small electric motor hrough reduction gearing mounted on the top plate F. lternatively, it may be turned by hand, either directly for uick adjustment of the position of the chuck B before nserting a specimen, or through part of the reduction gearing vhen carrying out a test. With a motor drive of constant peed, the rate of extension of the specimen is only constant f the deflexion of the load-measuring springs is negligible or roportional to the extension. However, when the elastic nd plastic components of the strain are of comparable nagnitude, an approximately constant rate of extension is nore readily achieved by operating the machine by hand; after the plastic range is entered, the load, and hence the deflexion of the load-measuring springs, increases less rapidly and the rate of turning must be decreased correspondingly.

By means of a microscope attached to the plate E of the frame, the specimen can be observed during straining. Vertical and horizontal adjustments provided in the clamp permit the whole surface of the specimen to be scanned.

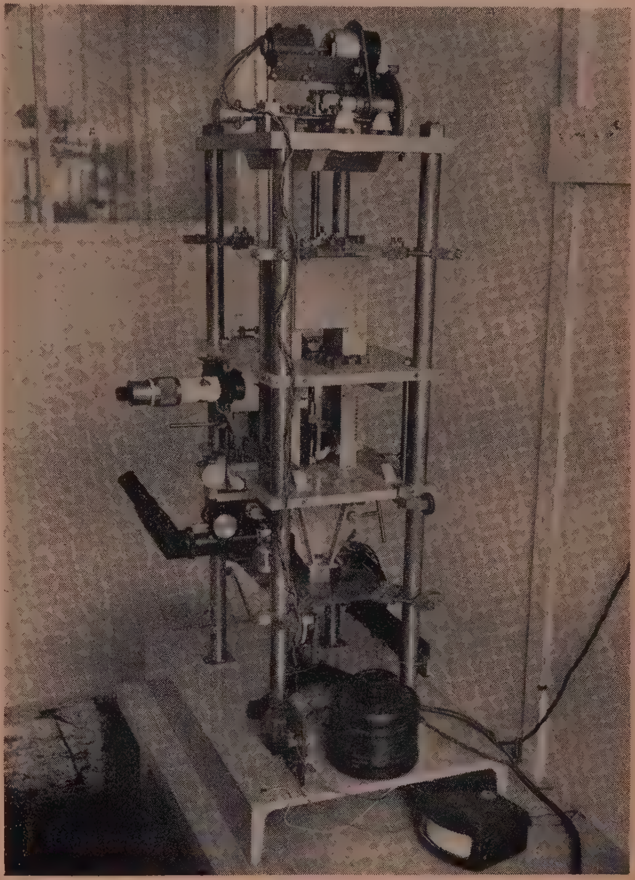


Fig. 2. View of machine with radiation shields removed

MEASUREMENT OF LOAD

As mentioned above, the load is indicated by the deflexion of the spring plates D, D', that is, by the movement of the rod C relative to the stiff plates E, E'. This displacement is measured by a roller and mirror device G_1, in conjunction with a telescope and scale (Fig. 1). The roller is held between the block L_1 which is attached to the rod C, and the block M_1 which is connected by a pair of spring strips to the plate E. There are two points of contact of the roller with L_1 and one with M_1.

The use of extra mirrors permits the scale to be attached firmly to the base of the machine and the telescope to project to the front (that is, normal to the plane of Fig. 1). The telescope is of ×15 magnification in order to achieve high sensitivity without sacrificing compactness. The same telescope is used for both load and extension gauges, one half of its aperture for each.

The load gauge is calibrated by hanging weights from a suitable yoke attached to the upper chuck A. For loads up to at least 25 kg, the calibration is found to be linear.

If a roller of $\frac{3}{64}$ in. (1·19 mm) diameter is used in the load gauge, the smallest interval on the scale corresponds to a load change of 13·5 g and the total range is 6·8 kg (or ±3·4 kg). Thus, by estimating to one-tenth of a division, the sensitivity of the load gauge with this roller is approximately 1 g. If a larger roller is used, the load range is increased and the sensitivity decreased in proportion to its relative diameter.

MEASUREMENT OF EXTENSION

Since it is not feasible to attach a conventional strain gauge to a small single crystal without damaging it, it is most convenient to measure the overall extension. In the present apparatus, this is done by observing the displacement of one chuck relative to the other by means of a roller and mirror gauge G_2 mounted between the yoke H and the rod C.

The design of the extension gauge G_2 is identical to that of the load gauge G_1 except for a temperature–compensation feature to allow for the difference in thermal expansion between the specimen and the surrounding steel parts. Instead of the roller being in direct contact with the block L_2, it bears on a downward projection from the latter, made of a suitable material; for example, if the specimen is of copper, the projection could be an equal length of copper. As a result of this temperature compensation, the room temperature need not be controlled so strictly as would otherwise be necessary; maximum accuracy of measurement is still possible in spite of temperature changes of several degrees. However, the central parts of the machine must be protected from uneven heating due to radiation from the scale lamp or the operator's body. Cardboard shields are used for this purpose.

The method that has been used for calibrating the extension gauge is to compare its readings with those of a 1/10 000 in. dial gauge placed under the lower chuck, there being no specimen in the chucks. Since only a relatively small amount of the dial gauge range is used, the accuracy of calibration by this method is not very high, but it has been sufficient in the tests so far done in the machine, especially in view of the non-uniform state of strain at the ends of the specimens (for more accurate calibration, a strain gauge could be mounted between the chucks).

If a roller of $\frac{3}{64}$ in. (1·19 mm) diameter is used in the extension gauge, the smallest division on the scale corresponds to an extension of 21×10^{-6} cm and the range is 0·01 cm. Thus, by estimating to one-tenth of a division, the sensitivity is 2×10^{-6} cm or 10^{-6} strain in a specimen of 2 cm length.

If small strains are to be measured under high loads (for example, in the case of large elastic strains), it may be necessary to apply a correction for the deflexion in those parts of the machine between the chucks and the extension gauge. This correction may be obtained from measurements on a specimen of hard steel of known Young's modulus, loaded within its elastic range, by subtracting the calculated elastic extension from the observed "extension." The correction is of the order of 10^{-5} cm/kg load, and is negligible in most tests on single crystals. Alternatively, the complete calibration of the extension gauge would be obtained from measurements on two such elastic specimens of different diameters.

For the measurement of large plastic strains, when the deflexion of the load-measuring springs (about 10^{-3} cm/kg load) is negligible, a dial gauge placed below the lower chuck B can be used directly to indicate extension.

CHUCKS—A METHOD OF GRIPPING COPPER SINGLE CRYSTALS

The design of the chucks presents considerable difficulty. They are required to grip a soft single crystal so that tensile or compressive loads can be applied axially to it, but they must not damage the crystal while being tightened. The second requirement is very difficult to satisfy in any mechanical clamping arrangement. Although two coaxial shoulders may be cemented to a specimen with the aid of a suitable jig, it is very difficult to aline the chucks sufficiently accurately to prevent bending the specimen when the second chuck is being tightened.

The following method of clamping was evolved to circumvent these difficulties and has proved to be quite satisfactory for rod-shaped copper crystals. Mechanical clamping is only used for one end of the specimen; this end has a steel shoulder cemented to it with Araldite and the shoulder is firmly clamped in the upper chuck, which is of V-groove type. The lower chuck B (Fig. 3) is in the form of an electrically heated mould containing Comsol solder (5% tin, 1·5% silver, balance lead, chosen for its creep-resisting properties at room temperature). While the solder is molten, the specimen S is inserted with its steel shoulder C in the V-groove of the upper chuck A; the lower end of the specimen is then dipping freely into the molten solder, so that it will not be damaged while the upper chuck is being tightened on the steel shoulder. Next, the solder is allowed to solidify, thereby firmly gripping the lower end of the specimen; moreover, provided that the solidification proceeds uniformly on all sides, no distorting force will be applied to the specimen at the time of gripping. The subsequent thermal contraction is easily compensated by operating the machine by hand so as to keep the load equal to zero during cooling. Insulating washers of mica M minimize the flow of heat from the lower chuck to the other parts of the machine. While the specimen is hot, a stream of nitrogen is directed at it from two sides (Fig. 3) in order to prevent oxidation of the surface.

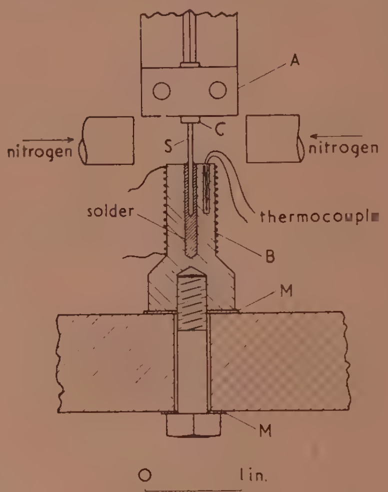


Fig. 3. Details of chucks

PERFORMANCE

Measurements of load and extension made on a specimen of silver steel of about 1·5 mm diameter, which was gripped by the method described above for copper crystals, are plotted in Fig. 4. As should be the case for the lower part of the elastic range of silver steel, the extension is proportional o the load and there is negligible hysteresis. Thus it may be concluded that:

(1) There is no significant hysteresis inherent in the measuring devices during cycles of load including both tension and compression.

(2) There is no significant hysteresis arising from the Araldite cement or the Comsol solder.

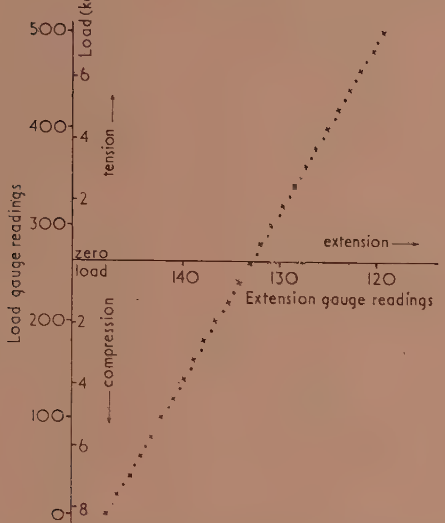


Fig. 4. Load and extension measurements for cyclic loading of a silver steel rod of 1·5 mm diameter. Load gauge roller = $\frac{7}{64}$ in. diameter; extension gauge roller = $\frac{3}{64}$ in diameter

× load gauge reading increasing.
● load gauge reading decreasing.

Further, no appreciable creep was found to occur in the Comsol solder or the Araldite cement when the specimen was eft under load for many hours.

As an example of the type of test for which the machine was designed, the stress-strain measurements for one cycle of deformation of a copper single crystal of 1·5 mm diameter are given in Fig. 5. This crystal had previously been given 320 similar cycles of reversed plastic deformation with an amplitude of 0·001 plastic resolved shear strain.

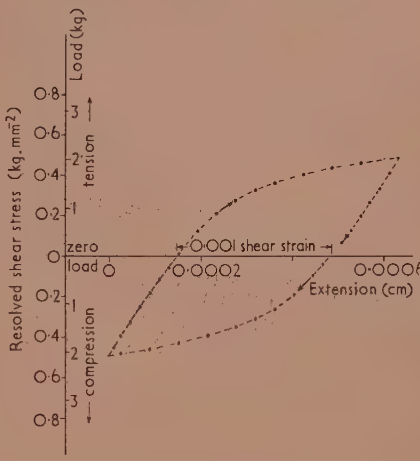


Fig. 5. Hysteresis loop measured on copper single crystal of approximately [111] orientation, after 320 previous cycles of same plastic strain amplitude

The machine has recently been used in a study of the effect of orientation on the strain hardening of copper crystals in reversed deformation.$^{(2)}$

ACKNOWLEDGEMENTS

This machine was designed while the author was on the staff of the Department of Supply, Melbourne, and the main part of the construction of the machine was done in the Department's workshops, while later improvements were made at the Australian National University.

This description is published by permission of the Chief Scientist, Department of Supply.

REFERENCES

(1) Held, H. *Z. Metallkunde*, **32**, p. 201 (1940).
(2) Paterson, M. S. *Acta Metallurgica.* To be published.

An apparatus for measuring the visco-elastic properties of coal in the course of carbonization

By D. Fitzgerald, M.A., B.Sc., National Coal Board, Central Research Establishment 1, Stoke Orchard, Glos.

[*Paper received* 28 *June*, 1955]

The apparatus, which allows the strain-time relationship for a briquette upon application and removal of a sudden stress to be observed, shows that an increasing viscosity is accompanied by an increasing elasticity which is retarded. Constructional details are given, with the results of one representative experiment. The possible application of the apparatus to studies of stresses and cracking in coke oven charges is indicated.

The elastic and viscous properties of coal while carbonizing ave recently become of theoretical as well as practical nterest, particularly in connexion with the study of the tresses produced by contraction. Normally the semi-coke roduced from the softened coal is assumed to be a brittle solid,$^{(1)}$ whereas it is initially actually capable of plastic flow upon application of stresses, which can thus be relaxed.

There exists a considerable literature on the measurement of the apparent viscosity of coal during carbonization (see Lowry$^{(2)}$ for a review and Echterhof$^{(3)}$ for a recent paper on this subject), but no measurements have been found by the author on the elastic properties of coal in the plastic and post plastic regions. Such properties must exist at the same time as the viscous properties, as the apparent viscosity is observed to increase without limit as decomposition proceeds, and nothing which could be interpreted as a solidification point with discontinuous changes in physical properties is observed, so that as fluid properties vanish elastic properties develop.

It is possible to observe viscous properties without reference to any elasticity that may exist or develop by the use of a constant stress. The reverse is not possible, so that if a changing stress is used to produce recoverable elastic strains, these can only be separated from the irrecoverable viscous strains by the use of a valid theory of the viscoelastic nature of coal. A note on such a theory has been published(4) and a fuller treatment will follow. In brief, it has been shown that coal can be represented by a model consisting of a Maxwell body in series with a Kelvin body.(5)

The author has been encouraged by discussions with other workers to describe the apparatus which has been used for this work. In principle it is the simplest possible device for relating stress and strain: a known force is applied to a briquette of known cross-section, and the strain-time relationship is observed.

The details of the apparatus (illustrated in Fig. 1) are as follows. A 1 in. internal diameter silica tube *A*, 8 in. long, is divided into two approximately equal portions by a silica partition *B* normal to the axis of the tube. The tube is wound as an electric furnace for the central 5 in. of its length using nickel-chrome resistance tape. The upper portion of the tube contains the coal to be experimented upon in the form of a binderless briquette *C*, 0·5 in. in diameter and about 0·4 in. high, made of coal ground to below 0·2 mm in size. This briquette is compressed by a silica rod *D* through a silica plate *F* of diameter slightly greater than 0·5 in. At its upper end the silica rod *D* is attached to the pan of a balance. Air is excluded from the upper chamber by a liquid seal *G* using a silicone fluid. This arrangement provides a frictionless sealing-gland at the entry of the rod *D* into the furnace and hence there is no friction loss in the force transmitted from the balance to the briquette *C*. Volatile matter from the carbonizing briquette leaves the apparatus through a small tube *H*, which is narrow enough to ensure that no air shall enter the apparatus by back-diffusion.

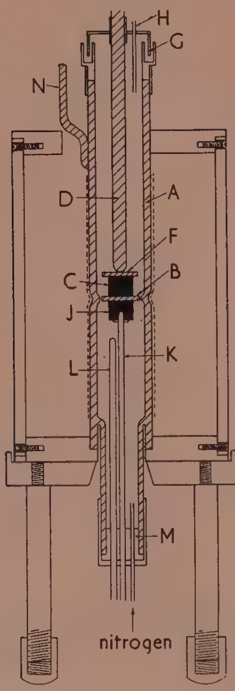


Fig. 1. Section of apparatus for measuring the visco-elastic properties of coal

The lower chamber contains a second briquette *J* identical with the first, pressed against the partition by a thin steel thermocouple sheath *K* containing a thermocouple to measure the briquette temperature. A second thermocouple in a sheath *L* is used to control the temperature, by means of a temperature programme controller. The lower chamber is sealed against the atmosphere by a further liquid seal *M*. Oxygen-free nitrogen enters the system *via* a tube through the latter. This nitrogen together with the volatile matter of the lower briquette pass into the upper chamber through either of two holes near the edge of the partition, whence they escape as already described.

The furnace, well lagged, stands on a rigid base fitted with levelling screws. Since the indicating assembly is very sensitive to external vibration the apparatus stands on a heavy support fitted with rubber feet.

The strain suffered by the briquette *C* is shown by the assembly illustrated in Fig. 2. This assembly consists of three separate parts. The main portion *R* is attached to the silica finger *N* (Figs. 1 and 2), and carries an upright to which lever *Q*, of channel-section, is pin-jointed. *R* also carries a hardened steel pin *T* (a gramophone needle) of adjustable height. The second portion is lever *P*, also of channel-section, but of slightly larger cross-section than *Q*. Lever *P* has a hardened cup on its underside in which rests the tip of *T*, and carries pins at each end, one fitting into a suitable slot on *Q*, the other pressing against the two knife edges *U*. These knife edges are on the third part of the assembly, which serves to transmit the movement of silica rod *D*, to which it is clamped, to the assembly. Vertical motion of *D* is converted into rotary motion of *P*, which is amplified in the rotary motion of *Q* by the ratio of the effective lengths of *P* and *Q*, which in turn is converted to vertical motion of a light spot on a scale using a galvanometer lamp with mirror *S*. It will be seen that though *P* is a removable member of the assembly, by virtue of its location by the cup within which needle *T* rests, the assembly needs calibrating only once, providing the upright supporting *Q* is not moved. The assembly gives a magnification of about 2000 with a scale 100 cm from mirror *S*.

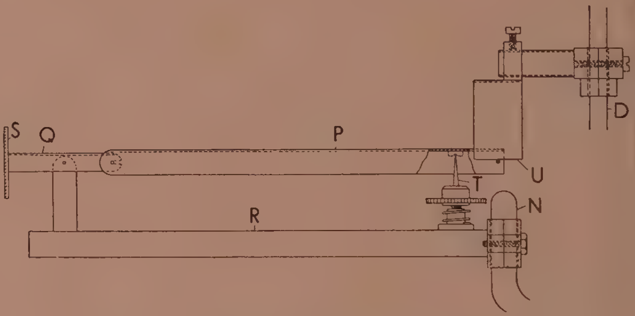


Fig. 2. Strain magnification assembly

Stress is applied to the briquette *C* by a syphoning system which allows known amounts of mercury to be quickly added to or removed from a vessel on the balance pan to which silica rod *D* is attached. In this way the rod is given the stability of the balance and, for small movements, constrained to move only in the vertical direction. Mercury is chosen because it allows the required stresses to be applied in a minimum of time, without shocks to the apparatus. The general arrangement of the apparatus is shown in Fig. 3, where *W* is the burette containing the mercury for applying and removing stress, *Y* is the strain-indicating assembly detailed in Fig. 2. *V* is the furnace, *E* is the balance and *X* is the receiving vessel for the mercury. *Z* shows the two thermocouples.

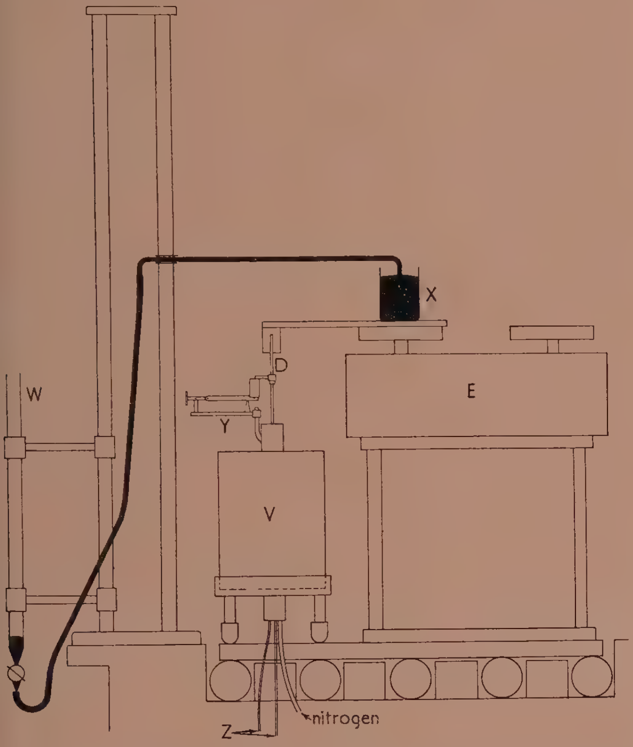


Fig. 3. General arrangement of apparatus for measuring the viscoelastic properties of coal

Fig. 4 shows the behaviour of a Barnsley seam briquette (coal rank code number 601, 36·7% dry, ash-free volatile matter) carbonizing at 435° C, when a stress of 77 400 dyn cm^{-2} is applied and again removed. Before and after stressing the contraction rates are $1{\cdot}6 \times 10^{-4}$ min^{-1} and $2{\cdot}4 \times 10^{-4}$ min^{-1} respectively. This is the contraction normal on carbonization, caused by the evolution of volatile matter and the consequent internal structural changes. If the mean of these rates is assumed to apply during stressing, the balance of the increased rate of strain observed ($3{\cdot}8 \times 10^{-4}$ min^{-1}–2×10^{-4} min^{-1}) or about 2×10^{-4} min^{-1} must be viscous flow. This corresponds to a viscosity of about 2×10^{10} poise. Young's modulus on loading and unloading is $3{\cdot}2 \times 10^{8}$ dyn cm^{-2}. This figure increases in the course of carbonization, until 5×10^{9} dyn cm^{-2} is reached, which is the highest value the apparatus will distinguish from absolute rigidity. The figure shows clearly that the elasticity of the briquette is retarded.$^{(6)}$

This method suffers from the following inherent difficulties. Firstly it cannot be used for highly swelling coals, as calculations are based on the assumption that the specimen remains cylindrical. Further, it is assumed that the whole top surface of the briquette is uniformly stressed, so that there must be no distortion, otherwise large errors are introduced. This means that only moderate heating rates can be used, so that the observed viscoelastic effects remain small. Higher heating rates would cause swelling and distortion of the briquette, owing to more rapid volatile matter evolution, but at the same time lower viscosities would exist, resulting in more marked viscoelastic effects, which would be uninterpretable owing to the violation of the original assumptions.

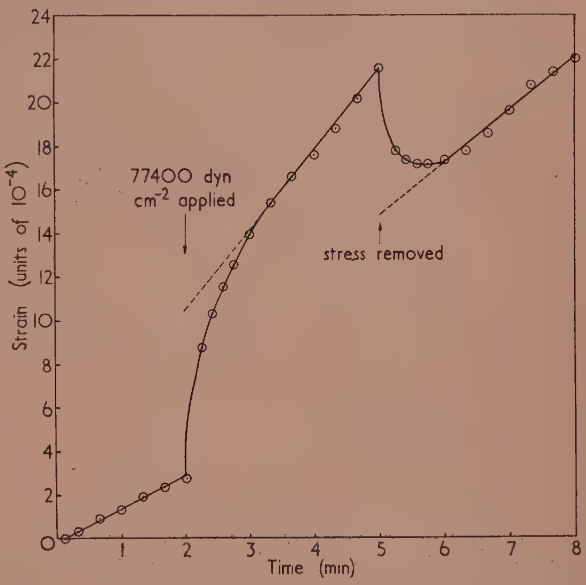


Fig. 4. Behaviour of a Barnsley seam briquette on application and removal of a stress

The instrument opens a new field in the study of coal carbonization. It has shown that materials which can be described as semi-cokes still have residual flow properties. These properties enable them to relax stresses which might otherwise cause cracking, and hence the phenomena observed using this apparatus are important in the study of cracking in the coke oven.

ACKNOWLEDGEMENT

This paper is published by permission of the Director-General, Scientific Department, National Coal Board. The views expressed are those of the author, and not necessarily those of the Board.

REFERENCES

(1) Soule, J. L. *Fuel*, **34**, p. 68 (1955).

(2) Lowry, H. H. (Ed.). *Chemistry of Coal Utilisation*, Chapter 6 (New York: J. Wiley and Sons, Inc., 1945).

(3) Echterhof, H. *Glückauf*, **90**, p. 510 (1954).

(4) Fitzgerald, D. *Nature [London]*, **175**, p. 515 (1955).

(5) Reiner, M. *J. Sci. Instrum.*, **22**, p. 127 (1945).

(6) Alfrey, T., Jr. *Mechanical behaviour of high polymers* (New York: Interscience Publishers, Inc., 1948).

Laboratory and workshop notes

The detection of the level of liquid sodium in stainless steel tubes

By E. W. Pulsford, B.Sc., A.M.Brit.I.R.E., Atomic Energy Research Establishment, Harwell, Berks.

[*Note received* 2 *September*, 1954]

Because of the necessity for handling liquid sodium in closed stainless steel apparatus, the detection of the level of the surface in vertical tubes presents certain difficulties, nearly all the common methods being either inapplicable or inaccurate.

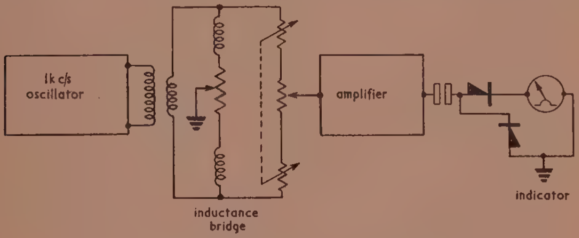
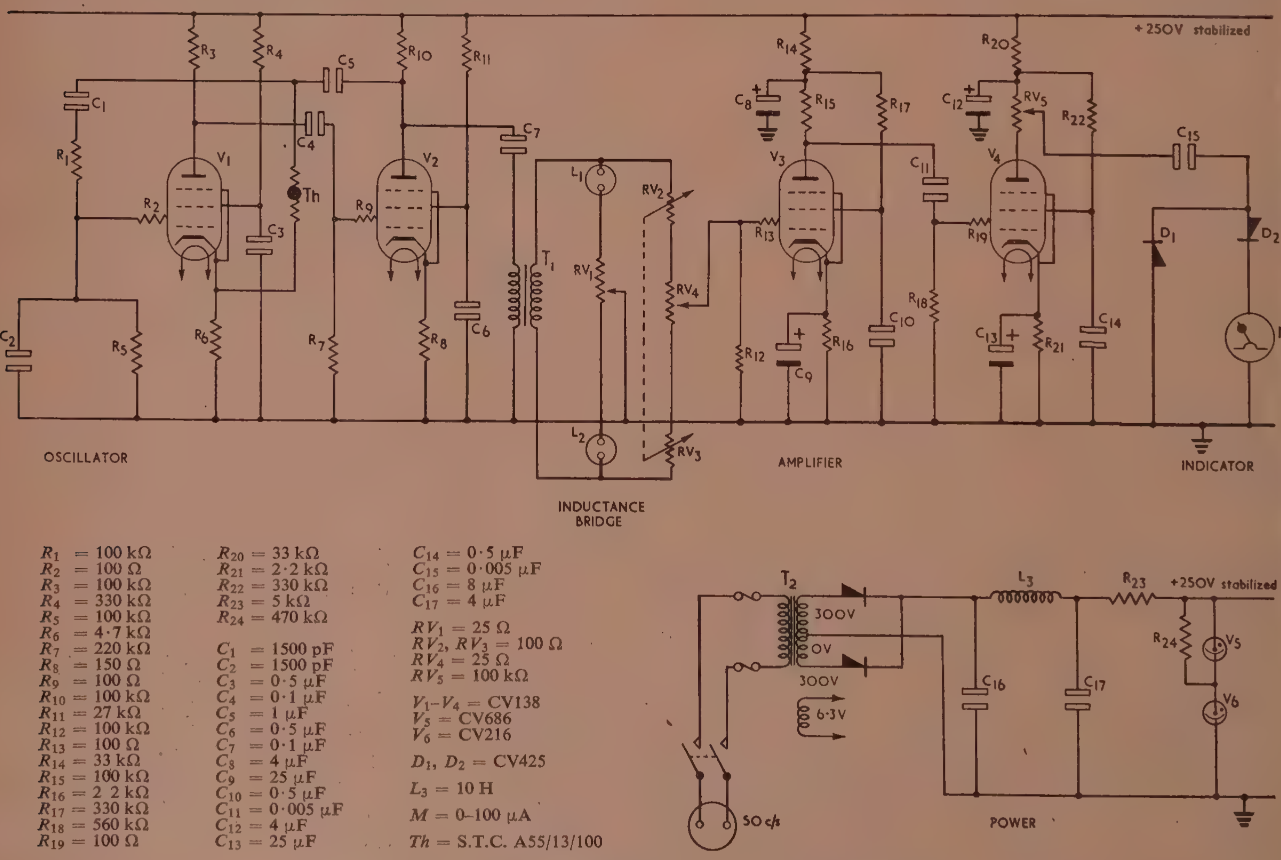

1k c/s oscillator
amplifier
inductance bridge
indicator

Fig. 1. Block diagram of level indicator

The tube is opaque to light; movable probes cannot be inserted because of the danger of inward leakage of moist air into the system, and consequent chemical action with the metal; and capacity methods fail because of the shielding effect of the metal tubes. Methods depending on the absorption of X- or γ-rays have been tried but are unsuccessful, the absorption of a full tube being very little greater than that of an empty one because of the relatively low density of liquid sodium. A method depending on the determination of the electrical conductivity of a short length of the tube is not very satisfactory because of the tendency of the liquid to stick to the inner walls.

A method has been devised depending on the change of inductance of a narrow coil of wire wound round the tube as the liquid surface passes through it. This succeeds because the tube material is but feebly magnetic, and the liquid metal is a good electrical conductor. Two similar coils are used, connected in a standard inductance bridge circuit, and the abrupt change in the state of balance of the bridge indicates when the liquid is threading one of the two coils. It is found convenient to mount both coils on the same tube, about 6 in. or more apart, with the search coil movable and the other coil fixed. The detector coils are each wound on a short length of Tufnol tubing, which is a sliding fit over the steel tube. The winding consists of 1000 turns of No. 40 s.w.g. enamelled copper wire, wave wound, with a width of $\frac{1}{4}$ in., the resistance is about 100 Ω, and the inductance about 250 μH.

The electronic circuits of the instrument are given in Figs. 1 and 2, and consist of a Wien Bridge oscillator, frequency 1 kc/s, coupled to the inductance bridge by means of a small 25 : 1 loudspeaker matching transformer. The bridge output is amplified by two stages of *RC* coupled pentodes, the output of the amplifier being rectified and shown on a moving-coil meter. Overloading of the meter is prevented by limiting the waveform applied to the rectifier


R3
R4
C5
R10
R11
R14
R20
+250V stabilized
C1
R1
V1
C4
Th
V2
C7
R2
C3
R9
L1
RV2
T1
RV1
RV4
C2
R5
R6
R7
R8
C6
L2
RV3
OSCILLATOR
INDUCTANCE BRIDGE
C8
R15
R17
C12
RV5
R22
C15
V3
C11
V4
R13
R19
D1
D2
R18
C10
R12
R16
C9
C13
R21
C14
M
AMPLIFIER
INDICATOR
T2
300V
0V
300V
6·3V
L3
R23
+250V stabilized
R24
V5
V6
C16
C17
50 c/s
POWER

R_1 = 100 kΩ
R_2 = 100 Ω
R_3 = 100 kΩ
R_4 = 330 kΩ
R_5 = 100 kΩ
R_6 = 4·7 kΩ
R_7 = 220 kΩ
R_8 = 150 Ω
R_9 = 100 Ω
R_{10} = 100 kΩ
R_{11} = 27 kΩ
R_{12} = 100 kΩ
R_{13} = 100 Ω
R_{14} = 33 kΩ
R_{15} = 100 kΩ
R_{16} = 2 2 kΩ
R_{17} = 330 kΩ
R_{18} = 560 kΩ
R_{19} = 100 Ω

R_{20} = 33 kΩ
R_{21} = 2·2 kΩ
R_{22} = 330 kΩ
R_{23} = 5 kΩ
R_{24} = 470 kΩ

C_1 = 1500 pF
C_2 = 1500 pF
C_3 = 0·5 μF
C_4 = 0·1 μF
C_5 = 1 μF
C_6 = 0·5 μF
C_7 = 0·1 μF
C_8 = 4 μF
C_9 = 25 μF
C_{10} = 0·5 μF
C_{11} = 0·005 μF
C_{12} = 4 μF
C_{13} = 25 μF

C_{14} = 0·5 μF
C_{15} = 0·005 μF
C_{16} = 8 μF
C_{17} = 4 μF

RV_1 = 25 Ω
RV_2, RV_3 = 100 Ω
RV_4 = 25 Ω
RV_5 = 100 kΩ

V_1–V_4 = CV138
V_5 = CV686
V_6 = CV216

D_1, D_2 = CV425

L_3 = 10 H

M = 0–100 μA

Th = S.T.C. A55/13/100

Fig. 2. Circuit diagram of level indicator

ircuit so that saturation of the second amplifier stage prouces full scale deflexion of the meter, or a little more.

In use, the bridge is balanced when both coils contain no quid metal, balance being shown by a sharp minimum on ne meter. Thereafter, as the surface rises in the tube, the neter shows a deflexion when the surface approaches the earch coil. The deflexion increases rapidly with surface novement towards the coil, eventually reaching a limit)·8 f.s.d.) when the surface is in, or somewhat above, the lane of the coil. This rapid meter movement indicates that ne rising surface is entering the search coil. The range of urface movement corresponding to the meter change from ne null balance point to the upper limit is thought to be bout ½ in. It is difficult to correlate with any great accuracy ne meter reading and surface position relative to the search oil because of the lack of an independent method of locating ne surface. The details quoted are those of a subsidiary xperiment using an aluminium rod in place of the liquid netal.

The method is used to indicate whether or not, during lling by pumping from below, the liquid metal surface has eached a certain point in the tubes of an experimental nstallation many feet high. Since the method has been evised to prevent overfilling, a high degree of accuracy is ot required.

Although this instrument has been developed for a specific urpose, it is conceivable that the method may have other pplications.

A circulation-system for ^{3}He

By K. E. A. Effat, Ph.D., A.Inst.P.* and J. H. Fremlin, M.A., Ph.D., F.Inst.P., University of Birmingham

[*Note received* 2 *November*, 1954]

or some time now the Birmingham 60 in. cyclotron has een used for occasional experiments with accelerated ions f ^{3}He. Since ^{3}He forms only one part per million in atmospheric helium, and ten times less in well-helium, only very mall ion beams of ^{3}He can be obtained when ordinary helium s fed into the source. Helium enriched in the isotope of nass 3 to 2% or more can be obtained from the Atomic nergy Research Establishment, Harwell, but a few cubic entimetres (measured at atmospheric pressure) cost several ounds and would only keep the cyclotron source supplied at s most efficient running pressure for two or three minutes.

It is thus very necessary to collect and recirculate the elium. If there were no leakage in the machine this would e simple enough, but all cyclotrons leak and a simple ecirculation without purification would lead to rapid conamination of the source gas. This would cause rapid eterioration of the filament and a general rise of pressure eading to breakdown. A system must be arranged, therefore, vhich will continuously remove air, water vapour and other esidual gases liberated from various heated metal structures, vhile maintaining a high rate of flow of helium.

A circulation system for this purpose has been described y Kundu, Donaven, Pool and Long,† using a liquid air trap ollowed by a liquid hydrogen trap.

The method used by the authors avoids the need for liquid ydrogen and is based on the fact that charcoal cooled to quid air temperature absorbs strongly all gases but helium. In Fig. 1 is shown a block diagram of the system. When the normal mechanical pump *A* is shut off the two main 14 in. oil diffusion pumps *B*, *B′* are backed by a 1 in. mercury diffusion pump *C* [by W. Edwards and Co. (London) Ltd.] with a backing pressure of 4 mm.

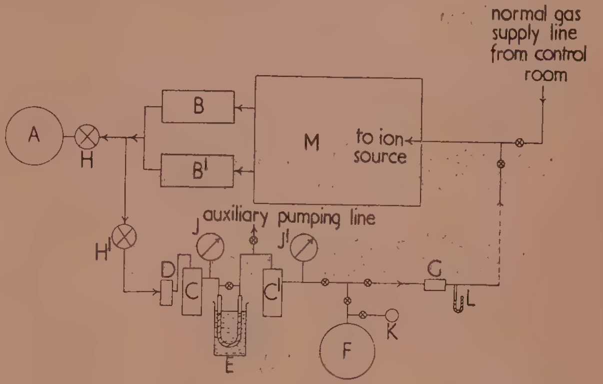


Fig. 1. Diagrammatic plan of the cyclotron vacuum and helium circulation systems

A, rotary pump; *B*, *B′*, oil diffusion pumps; *C*, *C′*, mercury diffusion pumps; *D*, liquid air trap; *E*, charcoal trap; *F*, helium reservoir; *G*, needle valve; *H*, *H′*, vacuum valves; *J*, *J′*, 0–20 mm dial pressure gauges; *K*, enriched helium bottle; *L*, Vacustat; *M*, cyclotron vacuum chamber.

The liquid air trap *D* removes water and oil vapour, which might otherwise choke the charcoal. Following the mercury pump, the gases pass through a stainless steel U-tube containing 35 g of activated charcoal *E*, which can be cooled in liquid air or heated to remove absorbed gases by means of a heating coil wound directly on to the tube over an insulating layer of asbestos paper. Details of the U-tube, showing how a good volume of charcoal has been combined with a low impedance are shown in Fig. 2. A second 1 in. mercury pump *C′* (Fig. 1) maintains the pressure gradient across the

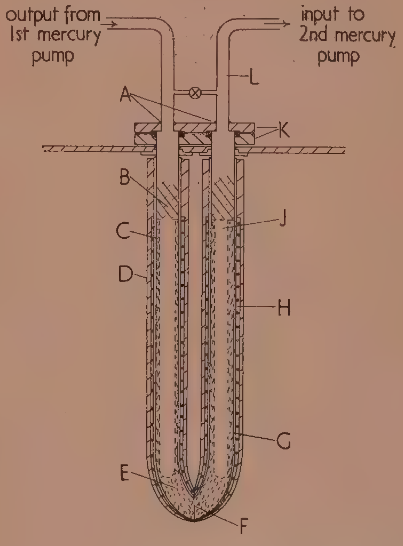


Fig. 2. Details of charcoal trap design

A, silver solder; *B*, glass wool; *C*, insulation; *D*, asbestos lagging; *E*, activated charcoal; *F*, welded joint; *G*, $\frac{3}{4}$ in. stainless steel tube; *H*, heater coil; *J*, wire gauze tube; *K*, brass flanges; *L*, $\frac{3}{8}$ in. copper pipe.

---

* Now at University of Cairo, Egypt.

† Kundu, Donaven, Pool and Long. *Phys. Rev.*, **89**, p. 1200 953).

charcoal and returns the purified helium through a needle valve *G* to the cyclotron source *M*.

With the normal air leak, which is between 1 and 2 cm^3/min at atmospheric pressure, this system will run perfectly for about eight hours without observable rise of the working pressure in the cyclotron tank (about 3×10^{-5} mm); the charcoal must then have absorbed more than half a litre of air at atmospheric pressure, apart from appreciable but unmeasured additions after changes of targets, etc.

After this time, the gas is shut off from the source, time allowed for all the helium in transit to be pumped into the reservoir *F* and the mechanical pump brought back into use. The system is then completely isolated from the cyclotron tank. With the help of bypass taps, both sides of the U-tube can be pumped at once by an auxiliary pump (not shown) while the charcoal is heated to about 400° C. It is important that the heater should not be put on while the U-tube is sealed off, or dangerous pressures may be generated. The process of heating and recooling of the charcoal may take half an hour. This has usually, during the two or three years of use, been arranged to fit with the experimental programme; if it were troublesome a second parallel charcoal trap could readily be inserted so that one could be in use while the other was being refreshed.

All parts of the present system have been made of metal. Glass rather than metal parts would make the system easier and cheaper to construct but, apart from general fragility, its use would make it desirable to use liquid nitrogen for cooling the charcoal rather than liquid air, to avoid the risk of explosion in case of fracture.

The authors are grateful to Dr. K. F. Chackett for his advice, particularly as to the quantity and quality of the charcoal needed.

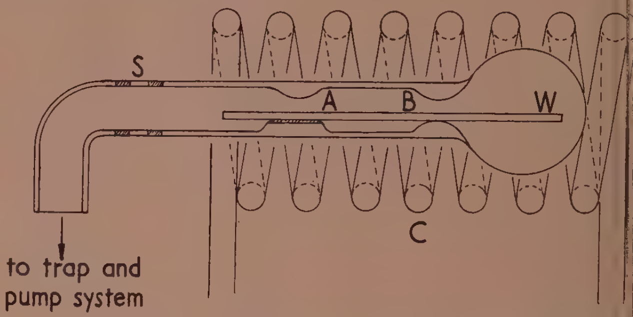
Heat treatment and sealing of metal electrodes into fragile glass bulbs under high vacuum

By N. Pentland, M.Sc., Ph.D., F.Inst.P., Brighton Technical College, J. O'M. Bockris, Ph.D., D.Sc., F.R.I.C., University of Pennsylvania, U.S.A., and E. Sheldon, B.Sc., Grad.Inst.P., Acton Technical College, London

[*Note received* 7 *February*, 1955]

A method for sealing metal electrodes into glass bulbs in an atmosphere of hydrogen with the object of maintaining the electrode surface free from oxide and other films has been reported.(1) Such electrodes are required for electrolysis in systems in which oxygen and other de-polarizing impurities must be eliminated. However, such films cannot be removed from certain metals by the technique described, because of the comparatively low maximum temperature (about 550–600° C) which can be employed. Greater efficacy in removal of oxide and other films may be obtained by heating the electrode strongly in high vacuum. This method also leaves the metal surface in a more reproducible condition and by heating the interior of the bulb, prevents the deposition of impurities thereupon, the volatilized impurities being removed into the vacuum train and condensed.

A 12 cm length of arsenic-free GSC glass tubing (by Chance Bros. Ltd.), 4 mm internal diameter, was rigorously cleaned. Two thickened constrictions were made near one end of the tube and a fragile bulb was blown at this end. The metal electrode wire *W* (e.g. molybdenum, in the present instance), approximately 5 cm in length, 0·1 cm in diameter and of spectrographic purity, was then introduced and arranged so that 1 cm projected into the bulb without touching the sides, being attached lightly to the glass by heating constriction *A*, as shown in the diagram. The tube was then fused horizontally to a Pyrex glass pump head, Chance GSD glass forming an intermediate seal *S*, and was evacuated to a pressure of 10^{-5} mm of mercury or less. The electrode tube was surrounded by the coil *C* of a radio-frequency heater, the coil consisting of seventeen turns of 6 mm diameter copper tubing wound into a solenoid 8 cm long and 1·5 cm diameter. A current of 85 A (at 270 V) was passed through the heater causing an induced current in the electrode wire *W*, sufficient to raise it to white heat in about two seconds. The heating was continued for one minute and the temperature of the wire was estimated by a disappearing filament pyrometer to be approximately 2000° C. The heater coil was then withdrawn, and a seal over the wire was made by heating the glass constriction *B* near the bulb cautiously with an oxy-gas flame. The final metal/glass seal was 2 to 3 cm long, and approximately 1 cm of wire projected freely into the bulb. Lastly, the electrode tube was drawn away from the GSC/GSD seal at *S* by application of the blowpipe flame.



Arrangement for radio-frequency heating and sealing of electrodes

In subsidiary experiments, the molybdenum/GSC glass seal was proved to be vacuum-tight, and it was also found that a film of oxide on a heavily-oxidized molybdenum wire sample appeared to be completely removed by the treatment described, as observed by microscopic examination and by hydrogen overpotential measurements. Norton and Marshall(2) have heated molybdenum to 1760° C in high vacuum in order to outgas the metal of such gases as carbon monoxide and nitrogen.

The technique has also been applied, using Hysil glass, to electrodes of palladium and of iron spot-welded to platinum, the seal in these cases being made over the metal/platinum junction and extended along the platinum. With both of these metals some difficulty was encountered at high temperatures owing to evaporation on to the interior of the bulbs.

The authors wish to acknowledge with thanks the interest and facilities provided by Mr. D. J. Pacey at Acton Technical College; one of us (E. S.) wishes also to thank the Chemical Society and the Central Research Fund Grants Committee of London University for financial support.

REFERENCES

(1) Bockris, J. O'M., and Conway, B. E. *J. Sci. Instrum.* **25**, p. 283 (1948).

(2) Norton, F. J., and Marshall, A. L. *Amer. Inst. Min. Met. Engrs, Prepr.* No. 65 (1932).

Correspondence

simple method of determining the shrinkage factor of nuclear research emulsions

i the course of an investigation(1) to measure the elastic cattering cross-section of 950 MeV protons using the free ydrogen present in Ilford G5 emulsion, it has been necessary o determine accurately the shrinkage factor of a large number f emulsions. There are several ways in which this may be one,(2) but most methods are rather laborious. We have ound the following method to be both simple and accurate.

Immediately after exposure to the beam of the proton ynchrotron the thickness of each emulsion, together with its lass backing, is measured at its centre point using a dial icrometer (by T. Mercer Ltd.). This instrument can be ead to ¼ μ; each scale division is 1/10 000 in. and the diameter f the dial is 2 in. The measuring foot is about 7 mm in iameter and slightly spherical in shape, the area of contact eing about 1 mm². During measurement the plate rests n four bearing balls, the centre one being slightly higher ian the other three. A similar arrangement has already been escribed.(3) Readings are taken at the centre point as etermined by a template; they are found to be reproducible o better than ½ μ. No deformation of the emulsion by the ieasuring foot has been detected.

After the plates have been processed and dried the thickness f each one is again measured at the same point as previously. hus the shrinkage of the emulsion s is obtained directly. An ik dot is then placed over the emulsion at the centre point s determined by the template. The thickness t'_0 of the mulsion itself at several points immediately adjacent to the ik dot, is then measured to the nearest micron on a type 1.4000 microscope using a ×95 oil immersion objective, ocused first on the top and then on the bottom of the mulsion; if the refractive indices of the oil and the emulsion re equal, the thickness is given directly by the distance ioved. This measurement is made immediately after the ial micrometer measurement. The microscope fine focus cale and the dial micrometer are calibrated using standard ip gauges. The original thickness t of each emulsion at its entre point and at the time of exposure is then given by $= t'_0 + s$. The value of t so obtained is independent of ny changes such as may be caused by variation in humidity etween the first and second measurements with the dial icrometer, but it is assumed that there is no change in umidity between the second measurement with the dial icrometer and the measurement by microscope.

The thickness of the layer may change subsequently nainly by variation of humidity). To determine the shrink-ge factor k at the time of observation and measurement of e plate, the thickness t' of the emulsion around its ink spot measured by the microscope at the time in question. The rinkage factor is then given by $k = (t'_0 + s)/t'$. This value assumed to be the same over the whole area of the nulsion; it is not necessary to assume this for the original ickness.

When the shrinkage factor of the emulsion is required ccurately, the difference between the refractive indices of nulsion and microscope oil cannot be neglected. This has een demonstrated experimentally by obtaining a value of e shrinkage factor using dial micrometer measurements one. It was found that the two values differed by about 1½%. An approximate calculation showed that this discrepancy could be accounted for by increasing the microscope thickness measurements by a factor equal to the ratio of the refractive indices of oil and emulsion.(2) The accuracy of the final result, using both micrometer and microscope measurements, is of the order of 1%. Values of the shrinkage factor obtained in this way for a typical batch of ten 2 in. × 2 in. × 400 μ Ilford G5 emulsions developed in Amidol varied from 2·46 to 2·52 when measured at a relative humidity of about 60%. The values obtained for the original thickness varied from 395·5 to 421 μ. There appears to be no correlation between shrinkage factor and original thickness.

This method of measuring the shrinkage factor is found to be complicated by two related factors. Firstly, the refractive index of the emulsion varies markedly with the relative humidity, and secondly the emulsion takes some time to obtain equilibrium with the water vapour content of the atmosphere.(3) It is proposed therefore only to make measurements of the dip angles of proton tracks(1) and of emulsion thicknesses after the plates have been stored in a constant humidity chamber for several days.

We are indebted to Mr. J. E. S. Robinson for technical advice and help.

Physics Department,
University of Birmingham.

P. J. Duke
W. O. Lock
P. V. March
B. A. Munir

REFERENCES

(1) Duke, P. J., Lock, W. O., March, P. V., Hughes, I., Muirhead, H., Gibson, W. M., and McKeague, R. *Phil. Mag.*, to be published.

(2) See Gailloud, M., Haenny, C. H., and Weill, R. *Helv. Phys. Acta*, **27**, p. 337 (1954) for a list of references.

(3) Oliver, A. J. *Rev. Sci. Instrum.*, **25**, p. 326 (1954).

The effect of the filter absorption edge in X-ray integrated intensity measurements

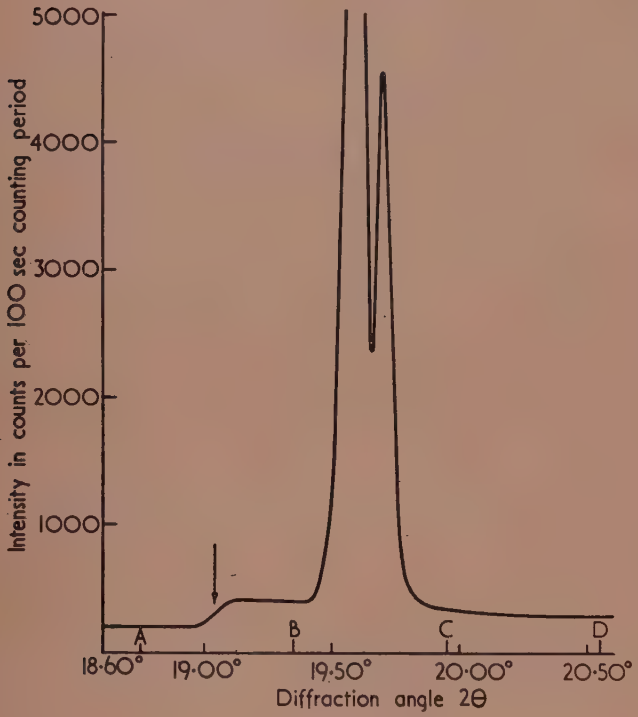
This note draws attention to errors which may arise in the measurement of integrated intensities of X-ray diffraction lines using the wide-slit technique* when a filter is used to eliminate Kβ radiation. Although the phenomenon is essentially well-known, it is believed that its effect in this context has not been described previously.

Such measurements are made using a detector slit wide enough to embrace the whole, or greater part, of the diffraction line, the intensity registered in this central position, *BC* in the figure, giving the intensity of the line plus background. Counts in immediately adjacent positions, *AB* and *CD*, are then taken to determine the background intensity and it is here that error may arise. Due to the absorption edge of the filter there will be a sudden diminution in the background intensity on the low angle side of the line, and if its position is sufficiently close to the line, the count in position *AB* corresponds to considerably less than the true background level at *B*.

---

* Coyle, R. A., Hale, K. F., and Wainwright, C. *J. Sci. Instrum.*, **30**, p. 151 (1953).

The figure shows this effect observed with molybdenum radiation and zirconium filter, the line being the (111) reflexion from an annealed copper powder compact. Since the background intensities on opposite sides of the zirconium absorption edge are approximately 2·0 and 4·0 counts per second measured with a narrow slit, the background count in position *AB* corresponds to 3·0 counts per second instead of the true value of 4·0 counts per second, a 25% error, and therefore the mean background intensity obtained from positions *AB* and *CD* will be in error by half this amount.



Line profile of copper (111) reflexion using filtered molybdenum radiation. Arrow denotes filter absorption edge

In this particular case of a strong line the mean background count with a wide slit is approximately 20% of the total integrated intensity of the line. Therefore the error of 12½% in the mean background count produces an error of 2½% in the measurement of the line intensity. With weaker lines the effect will be correspondingly greater.

While the effect is clearly evident in this instance owing to the proximity of the zirconium absorption edge, any line in a diffraction spectrum will have an associated "step" in the background if a Kβ filter is used, regardless of the type of radiation, and for higher order reflexions it may be sufficiently removed to lie in the vicinity of a neighbouring line. It should be noted that the sharpness of this edge was revealed only by very careful alinement of the diffractometer.

The work described above has been carried out as part of the General Research Programme of the National Physical Laboratory, and this note is published by permission of the Director of the Laboratory.

National Physical Laboratory, R. F. Braybrook
Teddington,
Middlesex.

Device for use with a non-recording microphotometer

Owing to the well-known difficulty of taking down the readings of a left-handed instrument,* we have provided our non-recording microphotometer with a variable-speed motor drive and a gear train, which gives a signal, preferably audible, at regular distances along the plate scan (in our case every 25 μ).

The galvanometer spot is allowed to wander as the plate traverses the system and the reading is taken down every time the buzzer sounds. In this way it is possible to treble the speed of scan over purely manual operation. The galvanometer should preferably have a short period to cut down the errors of dynamic operation, which will not exceed those of a recorder of comparable reaction-time.

A footswitch (Luneberg type) from a vacuum cleaner is inserted into the drive lead, so that the scan can be stopped for checking the zero of the galvanometer, or whenever there is any danger of the machine "running away" with the operator.

The device is much cheaper than a recorder, and gives about the same speed, when a moderate number of plates have to be examined.

Physics Department, G. L. Rogers
Victoria University College,
P.O. Box 196,
Wellington, New Zealand.

---

* Rogers, G. L. *J. Sci. Instrum.*, **30**, p. 437 (1953).

The preparation of thin bone sections

In a recent issue of this *Journal*(1) Jowsey describes the use of a milling machine fitted with H.S.S. screw slitting cutters for cutting sections of whole bone. The cutters are 0·020 in. thick and so this amount of material is lost for each section cut. The thickness of section apparently varies from 80 to 150 μ.

We have been using for several years a section-cutting machine for preparing bone sections for X-ray diffraction studies(2) but, instead of a cutter 0·020 in. thick, we used a resin-bonded carborundum wheel of 0·005 in. thickness. These wheels are 3 in. in diameter and are supplied by The Carborundum Co. Ltd. The machine was based on one designed by Atkinson(3) for cutting sections of teeth for microscope examination. Atkinson(4) also describes the embedding of specimens in methyl methacrylate. With these much thinner wheels only 0·005 in. of material is lost per section, and the serial sections are consequently much closer to each other, so that it is easier to follow structures from one part of a bone to another. We used speeds of approximately 7000 rev/min but Atkinson used only 2800 rev/min with the same kind of wheel. (The Carborundum Co. Ltd. will supply wheels of varying thickness from 0·005 in. upwards.) The thinnest sections which can be cut directly are 25 μ thick, which is less than that obtained by Jowsey after cutting and then hand-grinding. These thin sections can be cut serially and consistently, provided the apparatus is solidly constructed and is free from vibration of the individual parts.

We have used various embedding materials, including methyl methacrylate, and have found a cold setting polyester, known as Marco resin, very suitable and convenient. It is sold by Scott Bader and Co. Ltd., and, as it can be polymerized at temperatures as low as 20° C, it has some dvantages for biological material. Where time is important, s for example in the experiments of Jowsey where shortved radioactive isotopes are being used, the Marco resin nay have great advantages over methyl methacrylate. The naterials are always ready, needing no preparation apart rom mixing immediately before use, and polymerization akes place in a few hours at room temperature. Heating to 0° C speeds up the process even more.

One of us (J. I.) acknowledges a British Empire Cancer Campaign Research Fellowship.

University of St. Andrews,
Carnegie Laboratory of Physics,
Queen's College,
Dundee.

S. M. Clark
J. Iball

REFERENCES

1) Jowsey, J. *J. Sci. Instrum.*, **32**, p. 159 (1955)
2) Clark, S. M., and Iball, J. *Nature* [*London*], **174**, p. 399 (1954).
3) Atkinson, H. F. *Brit. Dental J.*, **88**, p. 29 (1950).
4) Atkinson, H. F. *Brit. Dental Ann.*, p. 144 (1952).

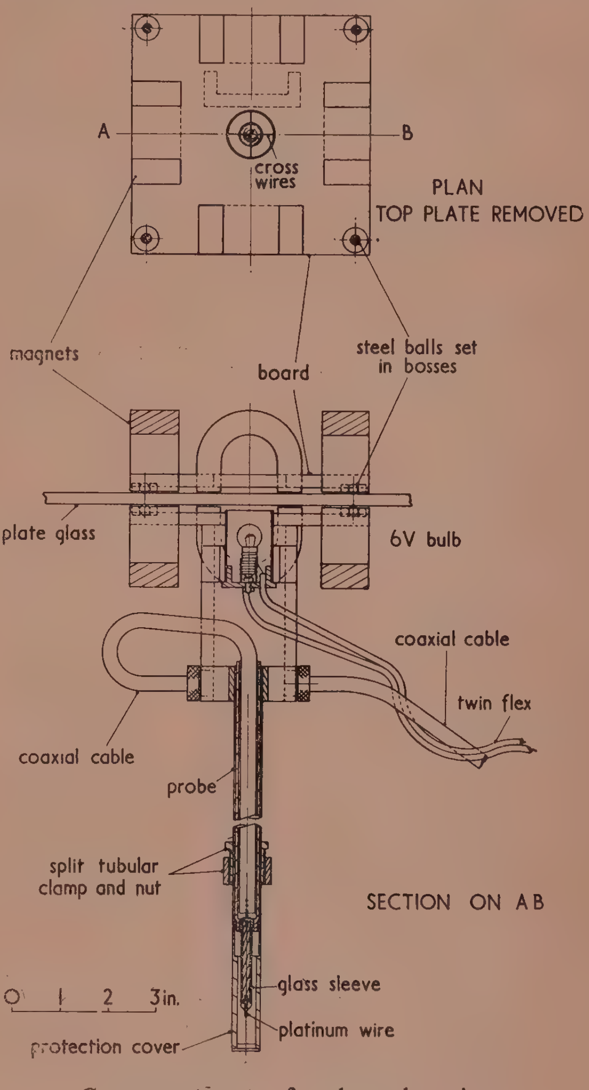
An improved probe assembly for use with an electrolytic tank

Hitherto the more usual method of supporting the probe in n electrolytic tank has been by means of a trolley travelling on rails and provided with some type of cross traverse. Arrangements of this kind are expensive to construct and umbersome to operate, and it has been possible to effect a onsiderable improvement by employing a new type of probe ssembly incorporating a magnetic carriage developed by Professor E. Bradshaw at the College of Technology, Manchester.*

In this arrangement (see figure) four magnets are fixed to ach of two plates which run on ball bearings on both sides of the transparent plotting table, one on the top and the other on the lower face. The attraction between the magnets s sufficient to keep the plates together, so that on moving the op plate the bottom plate follows perfectly. A probe with lluminated cross-wires directly above it is attached to the ottom plate so that the shadow of the cross-wires on tracing inen fixed to the plotting table marks its position. Compared with the conventional design, this arrangement is convenient s the probe may be moved in any direction with certainty. This not only saves time, but, by moving the probe at right ngles to the equipotential line being plotted, and hence along the greatest voltage gradient, the greatest sensitivity an be obtained.

A further advantage is that the construction is quick and nexpensive, and no precision machining is required.

The lead from the probe to the electronic equipment ssociated with the tank is stiffened in order to travel over he cylindrical side rail when the probe is moved, without agging into the tank. This stiffening is of flexible conduit which has been stretched longitudinally to form a close-fitting spiral round the coaxial lead. The optical system consists solely of a 6 V bulb with the cross-wires directly above it mounted very close to the underside of the glass. In this way no lens is required. The magnets are glued into slots in the plates of synthetic resin bonded paper board, by means of a synthetic resin adhesive, which is also used to fix the bosses in position.



Component parts of probe and carriage

Regular use of this form of probe over the past twelve months has fully substantiated the claims made for ease of operation and shortening of the time of plotting.

Witton Laboratories,
The General Electric Co. Ltd.,
Witton, Birmingham, 6.

M. K. Weston†

---

* Diggle and Hartill. *Proc. Instn Elect. Engrs*, **101**, (II), . 364 (1954).

† Now at the Science Museum, South Kensington, London.

Notes and comments

A catadioptric camera for ultraviolet spark photography

The printers regret that some reproductions of the discharge photographs that appeared in the above paper by J. Dyson, on p. 273 of the July issue, were defective in that thin white lines have been produced which were not present on the original photographs. It will be obvious to most readers who have defective copies that these lines are extraneous. A replacement page with better reproductions will, however, be supplied free of charge on request.

Review of electronic components for use in telecommunications

We have received a copy of the *Journal l'Onde Electrique* for March–April 1955. This is a special edition devoted exclusively to components for use in telecommunications equipment and has been sponsored by the French Society of Radio-Electricians. It comprises several papers by authorities in the field, on subjects ranging from resistors and capacitors to the recent developments on semiconductors. On the whole, the papers are intended for the general reader rather than the specialist, but even for the latter they constitute a useful review.

Copies of the Journal can be obtained from the publishers, Editions Chiron, 40 rue de Seine, Paris, 6^e. The price is 600 francs.

Radiological protection

The recommendations of the International Commission on Radiological Protection (revised 1 December, 1954) have been published as Supplement No. 6 to the *British Journal of Radiology*. They cover general principles of protection from ionizing radiations, including definitions of the scientific terms used, a report on permissible dose for internal radiation and a report on protection against X-rays generated at potentials of 5 kV up to 2 MV. The latter report includes a section on protection against X-rays from apparatus for non-medical applications. This section contains protection-data in the form of broad-beam attenuation curves, tables of barrier thicknesses and tables giving equivalent thicknesses of protecting material. Most of this data is given in terms of the thickness of material required to reduce the dose rate to 6 mr/h, this value being based on a permissible dose of 300 mr/week, assuming a 48-hour week.

No detailed protection-data are given for the gamma-rays from radio-isotopes, nor are the data on radium protective recommendations given in the 1950 recommendations reproduced.

The Supplement is available in paper covers from the British Institute of Radiology, 32 Welbeck Street, London, W.1, at 10*s.* 6*d.*

Glossary of terms used in radiology

The many new applications to radiology of discoveries in nuclear physics has made the need for a revised authoritative glossary long overdue. We therefore welcome the publication of British Standard 2597: 1955, *Glossary of terms used in radiology* which has been published by the British Standar Institution (price 10*s.* net). The 750 terms and definitio contained in it are divided into four main sections: Gener terms and physics; Sources of ionizing radiation; Radi graphy and fluoroscopy; Radiotherapy and radiation pr tection. A complete alphabetical index is included.

Exhibition of electrical standards and metering

A special exhibition has been opened at The Scienc Museum to coincide with the current meeting of the Inte national Electrotechnical Commission and will remain ope until 31 October. Although the Exhibition is of particula interest to those concerned in the problems of metering bul supplies of electrical energy to large industrial and com mercial undertakings, it is intended also for the less specialize visitor and serves to demonstrate the care which is devote to the accurate calibration of electricity meters.

One of the objects of the exhibition is to show the origi and derivation of the various electrical units. An exhibit o particular interest is the complete set of the original B.A units of resistance which were made in 1864 for the Britis Association and constitutes the oldest set of accurate electrica standards now in existence. These "B.A. Units" have bee stored for many years at the National Physical Laboratory It is now hoped that they will be presented formally to Th Science Museum, and thus become a part of the Nationa Collection of historic scientific apparatus.

The Science Museum, to which admission is free, is ope on weekdays from 10 a.m. to 6 p.m. and on Sundays from 2.30 to 6 p.m.

Symposium on magnetic materials

The electronics Group of The Institute of Physics will b holding a symposium on "Some recent developments i magnetic materials" in the Institute's House on 23 and 2 September, 1955. Seven papers will be read and discussed Further details may be obtained from the Institute at 4 Belgrave Square, London, S.W.1.

British Journal of Applied Physics

Contents of the September issue

SPECIAL ARTICLE

Alloys for use at high temperatures. By W. BETTERIDGE.

ORIGINAL CONTRIBUTIONS

An attempt to simplify coding for the Manchester electronic computer. B R. A. Brooker.

Instability of photomultipliers. By L. P. de Valencé.

A polarized light study of glass fibre laminates. By G. A. Horridge.

The appearance of some oscillating discharges. By T. K. Allen, R. A. Baile and K. G. Emeleus.

The measurement of elastic wave velocity in small cylindrical specimens. B N. B. Terry and H. J. Woods.

Thermal constants of pyrophyllite and their change on heating. By A. E. Carte

Discontinuities in the saturation curves of vacuum photocells. By J. S. Presto and G. W. Gordon-Smith.

Photoelectric recording of reflected echelon fringes. By T. A. Littlefield.

Millimicrosecond exposures by image tubes. By R. F. Saxe and R. A. Chippendale

NOTES AND NEWS

New books

Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principles, construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Square, London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation of contributions.* (Price 2*s.* 6*d.* including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon application from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, London, E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within 60 days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of address or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £4 per volume ($11.50 U.S.A.), including index (post paid) payable in advance. Single parts, so far as available, may be purchased at 8*s.* each ($1.15 U.S.A.), post paid, cash with order. Orders should be sent to The Institute of Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

The physics of the scintillation counter*

By G. F. J. Garlick, D.Sc., F.Inst.P., Department of Physics, University of Birmingham

The resolution and performance of scintillation counters used as energy spectrometers are limited by several factors due to the various physical processes involved. The spread in output pulse magnitude when detecting monoenergetic particles is, in the ideal case, due to the statistical fluctuations in the number of photoelectrons produced at the photomultiplier cathode and collected by the first multiplying stage. In practical usage contributions to the pulse spread may be due in particular to events in the scintillator and in the secondary emission processes in the multiplier. A critical discussion of the above factors is given and also of the problem of non-linear variation of phosphor response with energy and nature of the incident radiation.

he scintillation counter, comprising a combination of solid r liquid scintillator and a photoelectron multiplier, has ecome a powerful tool for radiation and particle detection nd energy measurement in nuclear physics. Its chief dvantages lie in its efficiency, particularly for γ-ray etection, its speed of response and the definite relation etween its output and the energy loss by the incident particle r radiation in the phosphor scintillator. Its energy resolu- on, when used as a spectrometer for particles, is still inferior that of the proportional counter, mainly due to low hosphor and photocathode conversion efficiencies. Over e past few years sufficient detailed studies of the counter ave been made to enable a clear estimate to be made of its sefulness and deficiencies in terms of the physical processes volved in each stage of the detector system from phosphor collector or output electrode. The purpose of this article to survey these processes in relation to the counter erformance.

Fig. 1(*a*) is a diagram of the usual scintillation counter stem. Fig. 1(*b*) is a schematic diagram of the number of ents which result from absorption of a monoenergetic article in the scintillator. The particle produces a number photons in the phosphor but only a fraction of these is collected by the photocathode *via* the light guide. An even smaller number of photoelectrons is created as a result and only part of this number is collected by and multiplied at the secondary emission dynodes. Fig. 1(*c*) shows in an approximate manner the effect of the change in numbers of events on the spread in output pulse distribution, assuming normal statistical fluctuations in these numbers. It is obvious that in the absence of non-normal variance the chief limitation to resolution (which may be expressed as the inverse of the variance of the output pulse distribution) is the relatively small number of photoelectrons collected at the first dynode, this number being mainly determined by phosphor energy conversion efficiency and photocathode efficiency. We now consider the processes in more detail.

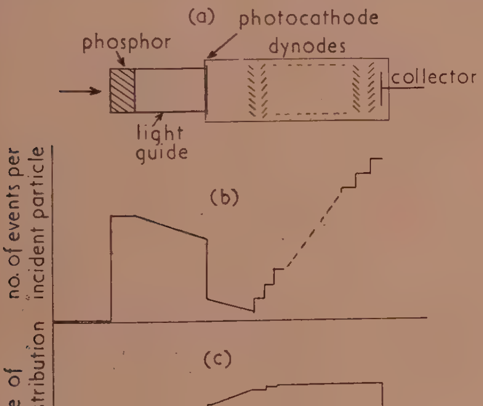

(a)
photocathode
phosphor
dynodes
collector
light guide
(b)
(c)
no. of events per incident particle
variance of pulse distribution

Fig. 1. Schematic diagram of scintillation counter and its performance

THE SCINTILLATOR

Discussion will be confined to crystal phosphors of inorganic and organic type since organic liquids generally show a similar behaviour to that of organic crystals.

The phosphor imposes four main limitations on counter performance as follows:

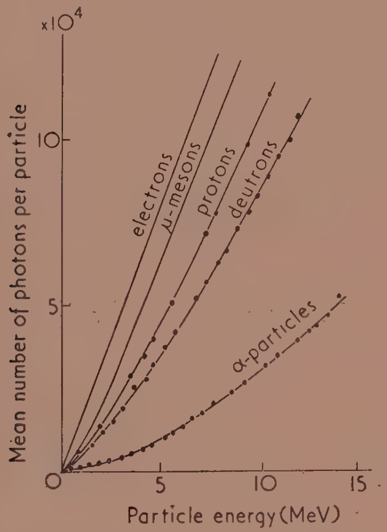
(*a*) Its response for conversion of absorbed energy into photons is less than 100% efficient. In some cases, e.g. zinc sulphide, efficiencies of 50% do not seem unattainable.(1,2) A discussion of the limit to efficiency has already been given by the author.(2) In inorganic phosphors such as zinc sulphide it depends on the existence of atomic centres in the phosphor in which radiationless recombination of excited electrons can occur. By contrast, in organic crystals ionization due to the incident particle is deleterious to radiative transitions in the constituent molecules. Hence the excitation efficiency varies with the primary particle involved. Densely ionizing particles (e.g. α-particles) give a lower efficiency than those giving low specific ionization (e.g. fast electrons). This problem also arises in the problem of linear energy response of the phosphor discussed below.

(*b*) The pulse spread or variance for numbers of photons due to successive particles may be non-normal, i.e. greater than expected for purely random fluctuations expected from the mean number of photons produced per particle. This is due sometimes to optical flaws in the crystal which affect the light collected per particle(3,4) or in some cases to unusual events along the particle track, e.g. in anthracene detecting α-particles knock on protons are produced near the end of the particle range which, having a different efficiency for exciting luminescence greater than that for α-particles and being about 15 in number, provide a relatively large contribution to the variance.(4) The resulting pulse height distribution tails out to higher magnitudes than for normal variance. A similar contribution to variance arises in diamonds due to singular events along the whole of the primary particle track.

---

* Based on a lecture given on 27 February, 1955, to a joint eeting of the Electronics Group and the Midland Branch of e Institute of Physics.

(*c*) The photon output of phosphors per incident particle is not always linear with particle energy particularly in the case of organic phosphors. Fig. 2 shows results collected by Wright⁽⁵⁾ for anthracene and for several different types of primary particle. It is seen that the more densely ionizing particles give the largest departures from linearity.



[Reproduced from *Physical Review*]

Fig. 2. Variation of the number of photons produced with particle energy and nature of particle for a crystal of anthracene (from G. T. Wright)

Wright has given a quantitative theoretical explanation of the non-linear effects as follows:

A molecule along the particle tracks may be ionized or simply excited. In the latter case it returns to normal either with emission of radiation (probability p) or by non-radiative energy loss (internal conversion, probability q). In the former case bimolecular recombination (recombination coefficient α) occurs and subsequent non-radiative loss of excitation energy is highly likely. The primary particle at a depth Δx in the phosphor loses energy $dE/dx . \Delta x = \epsilon_0 \Delta x$ in exciting or ionizing molecules. The rate of decrease of the energy is given by:

$$d\epsilon = -(p + q + \alpha\epsilon)\epsilon dt \tag{1}$$

The fluorescence ΔL from the path length Δx is given by:

$$dL = p\Delta x \int_0^\infty \epsilon dt = \frac{p}{\alpha} \log e\left[1 + \frac{\alpha}{p+q} \cdot \frac{dE}{dx}\right]\Delta x \tag{2}$$

For lightly ionizing particles (dE/dx very small) this gives

$$L \simeq E_0\left(\frac{p}{p+q}\right) \tag{3}$$

i.e. linear behaviour with efficiency limited only by the process of internal conversion. Using dE/dx values for anthracene extrapolated from range-energy curves in air, Wright gives theoretical L *versus* E_0 curves shown by the full lines of Fig for the different particles and closely agreeing with experime

(*d*) The phosphor decay time may be rather long. F organic phosphors this time is usually smaller than 10^{-} but this may be lengthened by photon reabsorption proces in the crystal.⁽⁶⁾ In the case of scintillation liquids dec times of millimicroseconds may be obtained but for inorga crystals decay times are often longer than a microseco From the fundamental point of view, for efficient phosph the limit is set by the transition probability p above. Fin values of the internal conversion probability q will speed the decay as also will bimolecular processes but b decrease the phosphor efficiency.

PROCESSES IN THE PHOTOMULTIPLIER

Fluctuations in pulse magnitude due to processes in photomultiplier have received considerable attention fr various workers as reviewed recently by Breitenberger The latter has given a very detailed analysis of multipl performance from which some points of particular inter may be selected.

The overall variance of the counter is given by Breite berger as ν_Q for the output pulses where

$$\nu_Q = \nu_X + T(1 - T)/T^2\bar{X} + \frac{\nu_M}{\bar{X}T} = \left(\nu_X - \frac{1}{\bar{X}}\right) + \frac{1 + \nu_M}{\bar{X}T}$$

where ν_X is the variance due to the phosphor conversi process, T is the transfer efficiency of photons from phosph through to the number of collected photoelectrons at first dynode. $\bar{X}$ is the mean number of photons produc initially and ν_M the contribution to variance from the mu plying stages. In the main, this formula resembles that giv by Garlick and Wright⁽³⁾ but they substitute in $\nu_M = 1/\overline{m}$ where $\overline{m}$ is the mean stage gain in the multiplying dynod In practice the potential between the photocathode and first dynode is made higher than that between success dynodes in order to improve efficiency of photoelectr collection. A further point made by Breitenberger is t the stage gain variance is usually not normal, i.e. $\nu_i > 1$ where i denotes the ith dynode. He suggests that this ari from detailed processes in the secondary electron emissi However, from Wright's analysis⁽⁸⁾ it seems more likely t non-uniform secondary emission response of the dyno surfaces is the cause. Wright considers this quantitativ and also a similar problem, namely, the non-uniform pho cathode response over its surface. The latter beco important when successive light pulses down the light gu do not fall on the cathode with identical spatial distributio

IDEAL COUNTER PERFORMANCE

As a conclusion we may note that for ideal performa a phosphor with no intrinsic variance contribution must chosen. Light collection must be as efficient as possible, also must photoelectron collection. When most non-nor contributions to variance are eliminated then equation reduces to:

$$\nu_Q = \frac{1 + \nu_M}{\bar{X}T}$$

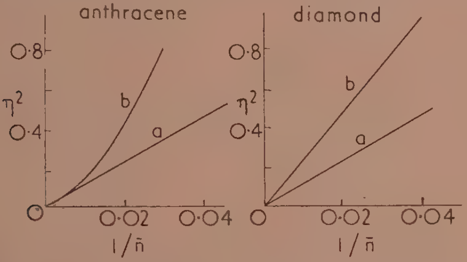
though ν_M must here include non-normal variance of dynode contribution.

Some factors have been omitted in the above survey lack of space, e.g. the problem of phosphor damage leterioration under bombardment, fatigue and after effects n the photomultiplier and the problem of short time esolution. In the latter, difficulties arise because of the luctuations or spread in transit times of photoelectrons and econdary electrons through the multiplier.(7)

With respect to possible improvements in the phosphor nd photocathode, the phosphor efficiency can possibly be mproved to be about 50% but end window multipliers have athodes with quantum efficiencies not greater than about 0% or so. Some improvement may be possible in the latter. Iowever, not more than a factor of ten is theoretically vailable to reach ideal conditions and so energy resolution vould still fall short of that of the proportional counter for articles completely stopped in the particular detector.

FUNDAMENTAL STUDIES ON SCINTILLATION PHOSPHORS USING THE COUNTER

It is not always realized that the use of monoenergetic articles to excite a scintillation phosphor and the use of the hotomultiplier to obtain the distribution in magnitude of he photon pulses per individual particle provide means of tudying detailed events in the interaction of the particle with he crystal lattice of the phosphor. As an example, some esults on anthracene bombarded by monoenergetic α-particles nay be mentioned.(3) If the phosphor response is ideal, then he variance of the output pulse distribution is proportional o the inverse of the mean number of photons produced by ach particle, or its measurable equivalent, namely, the mean umber of photoelectrons collected by the first dynode stage f the photomultiplier ($\bar{n}$). This relation is obtained in the xperiments of Garlick and Wright(3) by using light pulses f uniform intensity from a neon lamp working in a saw-ooth oscillator circuit. Curve (*a*) of Fig. 3 shows the linear relation obtained. The variance is represented by the square of the width of the pulse distribution η at half maximum ($\eta = 2{\cdot}36$ times the fractional variance of the distribution). Curve (*b*) of Fig. 3 gives the relation obtained for an optically perfect anthracene crystal when the α-particle energy is varied to alter the mean number of photons produced. It is seen that the extra variance introduced by events in the crystal increases rapidly as the energy or range of the α-particle is reduced, i.e. this effect is most probably due to events near the end of the particle range. Several possibilities exist:



[Reproduced from *British Journal of Applied Physics*]

Fig. 3. Variation of half-width of pulse distribution η with mean number of photons $\bar{n}$ produced by α-particles of different energies in anthracene and diamond (from Garlick and Wright)

(*a*) the α-particle changes its integral charge and so the value of dE/dx alters abruptly;

(*b*) the large dE/dx values at low energies imply large damage to the crystal at the end of the particle range;

(*c*) knock-on protons are produced especially after charge pick-up by the α-particle.

The extra variance is approximately consistent with the occurrence of knock-on protons. For 300 keV α-particles about fifteen knock-on protons are indicated which agrees approximately with the estimates made by Seitz.(9) The effects in diamond are quite different from those on anthracene and extra variance is associated with discrete events along the whole range of the particle in the crystal.

Scintillation techniques have been very little explored for such fundamental studies. They might be applied with profit to an investigation of the primary stages of damage in luminescent solids bombarded by high energy particles.

REFERENCES

(1) Bril, A., and Klasens, H. A. *Philips Res. Rep.*, **7**, p. 401 (1952).

(2) Garlick, G. F. J. *Brit. J. Appl. Phys., Suppl.* 4, p. S103 (1955).

(3) Wright, G. T., and Garlick, G. F. J. *Brit. J. Appl. Phys.*, **5**, p. 13 (1954).

(4) Garlick, G. F. J., and Wright, G. T. *Proc. Phys. Soc. [London] B*, **65**, p. 415 (1952).

(5) Wright, G. T. *Phys. Rev.*, **91**, p. 1282 (1953).

(6) Birks, J. B., and Little, W. A. *Proc. Phys. Soc. [London] A*, **66**, p. 921 (1953).

(7) Breitenberger, E. *Progress in Nuclear Physics*, Vol. 4 (London: Pergamon Press Ltd., 1955).

(8) Wright, G. T. *J. Sci. Instrum.*, **31**, p. 377 (1954).

(9) Seitz, F. *Disc. Faraday Soc.*, **5**, p. 271 (1949).

Simplified apparatus and procedure for freezing-point determinatio upon small volumes of fluid

By J. A. Ramsay, M.A., Ph.D., and R. H. J. Brown, M.A., Ph.D., Zoological Laboratory, University of Cambrid

[*Paper first received* 19 *January, and in final form* 7 *April,* 1955]

For purposes of determining the freezing-point of small volumes of aqueous solutions the difficulties of undercooling are avoided by first freezing the sample and then determining the thawing-point. Apparatus and procedure specially designed for simplicity of construction and operation are described. The method works best with volumes of the order of 10^{-3} to 10^{-4} mm^3 and its accuracy in terms of standard deviation is $\pm 0{\cdot}003°$ C for freezing-point depressions of the order of 1 to 2° C.

To be able to measure the freezing-point depression of very small quantities of aqueous solution is a matter of importance in invertebrate physiology. The main difficulty of the orthodox freezing-point methods, when applied to small volumes, is the difficulty of avoiding undercooling. Drucker and Schreiner(1) showed that this could be overcome by first freezing the sample and then warming it slowly so as to observe (with a hand lens) the disappearance of the last crystal of ice; the temperature at which this happens is the freezing-point, provided that certain precautions have been taken. This method was followed by Fritsche(2) and by Mosebach(3) who used samples of the order of a few mm^3 in volume. Jones(4) made use of the same principle by comparing the sample with a series of standards in respect of the order of thawing. Ramsay(5) and later Hargitay, Kuhn and Wirz(6) showed that the method was satisfactory with volumes of the order of 10^{-4} mm^3. Since then Kinne(7) has described a modification of Ramsay's apparatus and Zwicky(8) a modification of the apparatus of Hargitay, Kuhn and Wirz. Many other workers have made use of these already existing designs. Since this method appears likely to come into general use, the present authors have felt that it would be helpful to work out the design of an instrument which would combine the advantages of the various forms of apparatus already described.

DESIGN

Size of sample. All the thawing-point methods have the following procedure in common. The sample enclosed in a capillary is frozen and placed in a bath of fluid which is at lower temperature than the expected thawing-point; the bath is warmed slowly until the ice disappears and the temperature of the fluid in the bath is read from a mercury thermometer. It is assumed that the temperature of the sample is the same as that of the thermometer. But by reason of the poor thermal conductivity of water and glass and the large latent heat of fusion of ice, the temperature of the sample lags behind the temperature of the bath; and even with moderately small samples, e.g. 1 mm^3, and relatively slow rates of heating, e.g. $0{\cdot}01°$ C/min, the temperature of the bath is raised well above the thawing-point of the sample while ice is still present. With samples of the order of 10^{-3} mm^3, equilibrium is reached in a matter of seconds and it is possible to warm up the bath at a conveniently rapid rate without danger of overshooting the thawing-point. The use of small samples is therefore to be recommended even when economy of solution is not a consideration. The lower limit to the size of the sample is determined, in theory, by the effect of surf
tension in raising or lowering the hydrostatic pressure acc
ing to the curvature of the surface. From the surface tens
of pure water Hargitay, Kuhn and Wirz calculate tha
radius of curvature of $7{\cdot}5\ \mu$ corresponds to an error
$0{\cdot}002°$ C in the observed thawing-point. A spherical d
$7{\cdot}5\ \mu$ in radius is less than 10^{-6} mm^3 in volume. In pract
however, the useful lower limit is found to be about 10^{-5} m
and seems to be set by the increasing effects of slight c
tamination as the volume of the sample is reduced. The m
suitable size of sample for convenience of operation is 1
to 10^{-4} mm^3.

Observation of the sample. Sufficient magnification
samples of this size is provided by the ordinary low po
of the microscope (16 mm objective). One of the g
features of the method of Hargitay, Kuhn and Wirz is
the sample is held in a horizontal capillary tube and is vie
from above; the ice crystals, floating upwards to the mid-
of the capillary, are thus seen to best advantage. But th
offset by the disadvantage that the sample is mounted i
cuvette with a watertight lid, an arrangement which
obviously less convenient than the direct insertion of
sample into the bath as is possible with the other meth
Clearly the best of both systems can be secured by ha
the microscope vertical and the objective immersed while
capillary is mounted on a carriage which can be inserted i
the bath from above and then moved into position under
objective.

Temperature control. The requirements are that the b
can be cooled rapidly from room temperature to a
degrees below 0° C and thereafter maintained at a low
of cooling, the temperature being accurately controlled
means of an immersed heater wire. It seemed to the pre
authors that the most convenient means of cooling
to be sought in the use of dry-ice which has become gene
available in recent years. A simple system meeting t
requirements consists essentially of two concentric ves
both partly filled with 98% alcohol. Rapid cooling is
duced by adding dry-ice to the outer vessel, and slow coo
by removing the dry-ice to the inner vessel.

DESCRIPTION

The whole apparatus is shown in Fig. 1. It is house
a wooden box, 18 × 12 × 10 in., divided into two comp
ments, the freezing bath being on the left and the light so
and controls on the right. The bath itself, 7 × 7 × 8
and nearly all its fittings are made of Perspex which has

dvantage of allowing observation, but the disadvantage of eing attacked by alcohol stronger than 30%. The lid of ie bath is also of Perspex, 1 in. thick for purposes of heat isulation, and on it are mounted two incomplete vertical artitions of ¼ in. Perspex which divide the bath into four ub-compartments.

The impeller is in sub-compartment *A* (Fig. 1), the specimen arriage and thermometer are in *B*, the microscope is in *C* nd the cooler is in *D*; the heater lies between *A* and *D*. The 0% alcohol is driven down (and thoroughly mixed) in *A*, ises in *B*, descends in *C* and rises again in *D*. A special eature of construction is that metal parts running between he fluid in the bath and the upper surface of the lid, being aths of heat exchange and liable to cause condensation, are voided; the only exception is the spindle of the impeller hich is of stainless steel. Except for the stainless steel nirror all other metal parts are of chromium-plated brass.

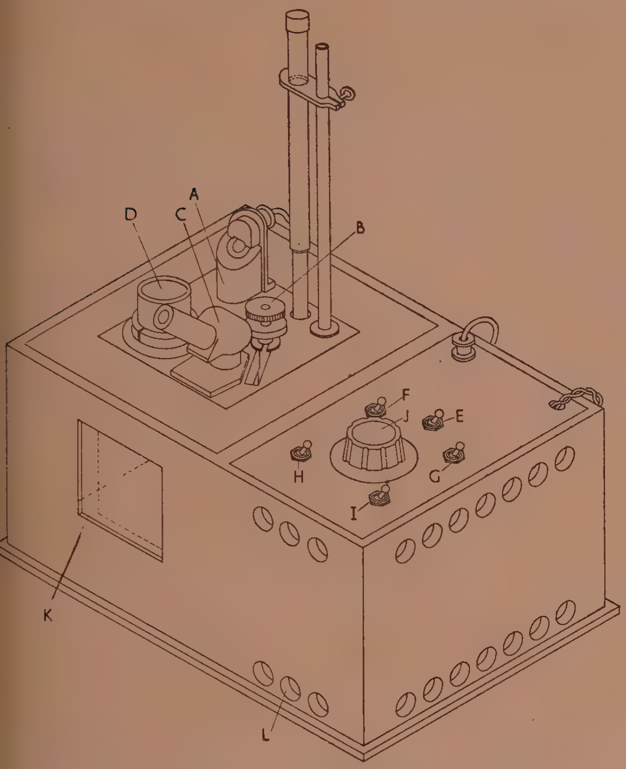


Fig. 1. General view of apparatus

A, impeller motor; *B*, specimen carriage; *C*, microscope; *D*, cooler; *E*, *F*, *G* and *H*, main, light, stirrer and heater switches; *I*, heater series resistance shorting switch; *J*, multi-way switch for control of heater series resistance; *K*, inspection window; *L*, holes for ventilation.

The cooler is also shown in Fig. 2. The vessels, since they ontain 98% alcohol, cannot be made of Perspex. The outer essel is of Pyrex glass; the inner vessel is of Tufnol and its ottom is fitted with seven brass rods ⅛ in. in diameter and f various lengths from ½ in. to 2 in. These serve to conduct eat between the outer vessel and the inner vessel, the rate f conduction being increased as the inner vessel is lowered nd more rods reach the alcohol in the outer vessel. The ner vessel is provided with a movable collar, in the form of Tufnol split ring sprung over it, by means of which its epth of immersion can be adjusted.

The heater (Fig. 3) is a grid of No. 22 gauge Nichrome wire (resistance 4 Ω). The impeller is 3 in. in diameter, with three blades, and is driven by a small electric motor (24 V, d.c.). The impeller rotates at about 250 rev/min and the circulation time of the fluid is about 10 s. The vertical vanes above the impeller are necessary to prevent the formation of vortices.

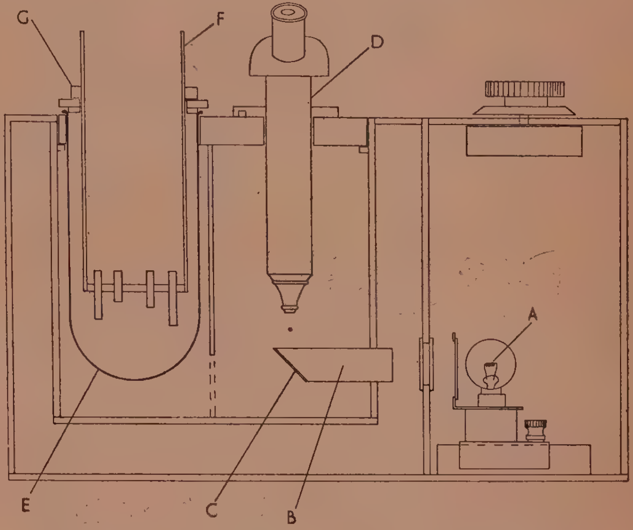


Fig. 2. Sectional view to show cooler and light path

A, light source; *B*, light guide; *C*, mirror; *D*, microscope; *E*, outer vessel of cooler; *F*, inner vessel of cooler; *G*, collar for setting height of inner vessel.

The microscope and specimen carriage are illustrated in Fig. 4. The specimen carriage guide is a slotted Perspex tube mounted upon the lid. The slot does not allow the specimen carriage to be rotated until it has been lowered to its full extent, when it can be swung round to bring the specimen into the field of the microscope. Adjustment in the other direction is provided on the microscope mounting and the focusing adjustment is incorporated in the specimen carriage.

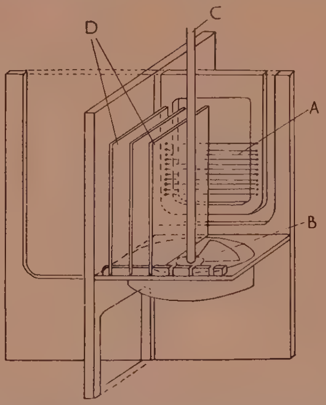


Fig. 3. Arrangements for heating and circulation

A, heater wire grid; *B*, impeller; *C*, impeller spindle; *D*, vertical vanes (three not shown) to prevent formation of vortices.

The objective is a Watson 16 mm (×10) and the eyepiece a Watson Huygenian (×6). The inclined eyepiece is a Watson inclination unit (×1·5) with the skirt removed and is located by the lower light tube which drops into the

Perspex tube of the microscope. Hargitay, Kuhn and Wirz used a polarizing microscope but in the authors' experience this is an unnecessary refinement.

The thermometer originally used in this and in the earlier version of the method was a Beckmann type with a 6° C scale graduated in hundredths of a degree. When not in use this had to be kept on ice since, if it rose to room temperature, there was risk of its going out of adjustment. A simple thermometer with a working range of 0 to −6° C, graduated in hundredths and capable of being raised to room temperature, has now been obtained and appears to be satisfactory.

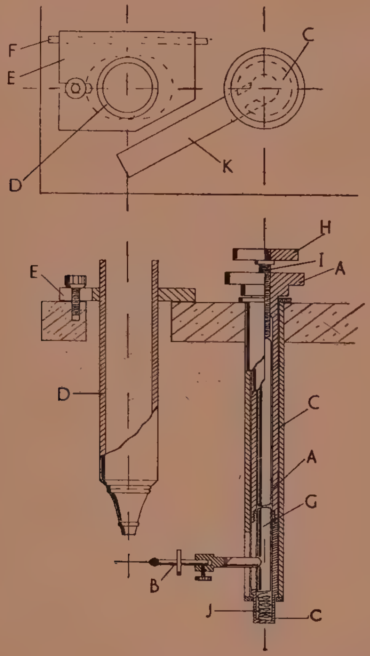


Fig. 4. Microscope and specimen carriage

A, A, specimen carriage; *B,* specimen holder; *C,* specimen carriage guide; *D,* microscope tube; *E,* plate carrying microscope tube; *F,* guide rod for plate; *G,* sliding rod for focusing movement; *H,* focus control; *I,* screw of focus control; *J,* return spring; *K,* slot in lid to allow passage of specimen holder.

The control panel on the right of the apparatus provides separate low voltage supplies for the light and for the heater, both 12 V, 3 A, a.c., and for the impeller motor, 24 V, 1 A, d.c. It is unnecessary to give further details except in the case of the heater circuit. This incorporates, in series with the heater, a set of resistors brought into circuit by a multi-way switch. The values of these resistors are chosen so that each step of the multi-way switch doubles the rate of heating. For rapid heating the series resistors can be cut out by the series resistance shorting switch.

A small Dewar flask, about 1½ in. in diameter and 3½ in. deep, is required in addition to the apparatus shown in Fig. 1. This is filled with 98% alcohol and dry-ice and is used for freezing the specimen before it is placed in the bath. Theoretically, this could be done in the inner vessel of the cooler, but in fact the level of alcohol in this vessel is too low for convenience.

OPERATION

Under this section are included the preparation of specimen tubes and the mounting of specimens, as well as the determination of the freezing-point using the apparatus j described.

The specimen tubes are made of silica; if Pyrex or oth hard glass is used the freezing-point of distilled water observed to fall steadily over a period of hours, suggesti that osmotically active substances are dissolved out of t glass. Ordinary size (e.g. external diameter ¼ in.) thi walled Vitreosil tubing is first drawn down to about $\frac{1}{32}$ diameter. A lump of Plasticine, about ½ in. in diameter, impaled upon one end of this tubing which is then he vertically with the Plasticine about 6 in. above the bench. fine oxy-coal gas flame (nozzle about 0·01 in. diamet cone about ¼ in. long) is allowed to play upon the tu about 1 in. from the Plasticine weight until the latter fal drawing out a fine tapering capillary. This is broken about ¾ in. from the beginning of the taper. This sili capillary is now mounted (with sealing wax) on a short leng of ordinary glass tubing connected to a rubber tube whi is held in the mouth [Fig. 5(*a*)]. If the greatest accuracy required a small quantity of boiling distilled water should sucked through the capillary, followed by air to dry it out.

In investigations of the body fluids of small animals it h been found convenient to keep the collection of body flu in a varnished watch glass under liquid paraffin; the use varnish (Bakelite Damarda) provides a hydrofuge surface a prevents the drop of body fluid from spreading out into film. The next part of the operation is carried out unde low-power binocular microscope. A small quantity of liq paraffin is first sucked up into the capillary, then a sm quantity of body fluid or other solution to be tested [F 5(*b*)]. This small quantity of solution—the specimen then sucked up the capillary, followed by liquid paraf until in the wider portion of the taper its length is of same order as its diameter [Fig. 5(*c*)]. It is often conveni to take up duplicate or triplicate specimens as illustrated Fig. 5(*f*). The sealing wax is now melted and the sil capillary is removed from its glass holder.

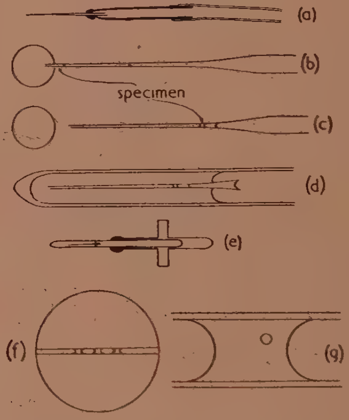


Fig. 5. Mounting of specimen

(*a*) Silica capillary mounted on glass tube with rubber connexion; (*b*) Specimen being drawn into capillary; (*c*) Specimen enclosed in liquid paraffin and drawn up to wider part o taper; (*d*) Capillary containing specimen broken off and enclosed in protecting tube; (*e*) Protecting tube mounted o specimen holder; (*f*) Triplicate specimens as seen in field o microscope; (*g*) To indicate size of remaining ice crystal a end point.

For its protection the silica capillary is enclosed in a wi tube of glass, about $\frac{1}{16}$ in. in diameter. This tubing is dra a point, liquid paraffin is sucked up for about $\frac{1}{2}$ in. and e point is then sealed in a micro-flame (the tube being held early horizontal, slightly inclined with the point upwards). he silica capillary is inserted into the open end of the procting tube, it is snapped off with forceps at the base of the per and the fine portion containing the specimen is pushed own until the specimen passes below the meniscus of the quid paraffin. Sufficient length of capillary should be left as to project above the meniscus, because with this arrangeent surface tension holds the capillary firmly against one de of the protecting tube [Fig. 5(*d*)]. The protecting tube then inserted into the specimen holder and fixed with ealing wax [Fig. 5(*e*)]. Apart from the preparation of the ubes, the process of taking up and mounting a specimen is ompleted in 2–3 min.

To bring the apparatus into action the inner vessel of the ooler is removed and pieces of dry-ice (about 100 g) re dropped into the outer vessel. With the apparatus itially at room temperature it takes about 30 min (and bout 2 lb dry-ice) to lower it to a few degrees below 0° C. s soon as the temperature of the bath is below the expected reezing-point any dry-ice remaining in the outer vessel is icked out and dropped into the inner vessel which is then laced in position and filled up with smaller pieces of dry-ice about 25 g). The specimen holder is now fixed in the pecimen carriage with the specimen uppermost. The pecimen is frozen by immersing it slowly (taking about 10 s) nto the alcohol of the Dewar flask and is then quickly emoved and placed in position in the bath. If, as is usually he case, there is still a great deal of ice present, the temperaure of the bath can be raised rapidly by the use of the series esistance shorting switch. The final approach to the end oint is, to some extent, a matter of the observer's taste. The authors prefer to find a setting of the multi-way switch hich will keep the temperature of the bath constant and hen to raise the temperature in very small steps by use of he shorting switch for short periods (e.g. 10 s). It has been alculated (Ramsay(5)) that the end point is effectively eached when the last crystal of ice is sufficiently small to be oncealed behind the meniscus [Fig. 5(*g*)] and persists for min. The determination of freezing-point takes 5–10 min.

After a determination has been made on one specimen it s often necessary to lower the temperature of the bath efore the next specimen can be tested. Lowering of the rder of a few hundredths of a degree can be brought about y dropping a small piece of dry-ice (about 3 g) into the uter vessel of the cooler.

PERFORMANCE

As stated earlier, the method works best with volumes of he order of 10^{-3} to 10^{-4} mm^3. A series of twelve determinations made on a 0·487 N solution of sodium chloride, sing specimens of the order of $2{\cdot}5 \times 10^{-4}$ mm^3, gave an verage value of $\Delta = 1{\cdot}678°$ C with a standard deviation of $\pm 0{\cdot}003°$ C which is less than $\pm 0{\cdot}2\%$. A similar series sing specimens of the order of 2×10^{-5} mm^3 gave an verage value of $\Delta = 1{\cdot}687°$ C $\pm\ 0{\cdot}014°$ C, which is greater han $\pm 0{\cdot}8\%$. The greater error with the smaller specimens s not due to the difficulty of observing the end point; it is possibly due to some contamination from osmotically active substances adhering to the silica.

Measurements of freezing-point depression were made on solutions of sodium chloride, the molalities of which were determined by chloride titration. These measurements are given in the table for comparison with figures calculated by linear interpolation of the precision data of Scatchard and Prentiss.(9)

Freezing point depressions of solutions of sodium chloride

Molality	*Δ Obs.*	*Δ Calc.*
0·755	2·535	2·552
0·495	1·680	1·675
0·2415	0·835	0·824
0·1272	0·445	0·439

Up to the present the method has not been fully tested on solutions other than those of strong electrolytes in water. There is no reason why it should not be used, with suitable modifications, on non-aqueous solutions. Beament(10) has determined the freezing-point depression of solutions of stearic acid and other lipoids in benzene, using glycerine instead of liquid paraffin. In a situation such that either the solvent or the solute may dissolve in the enclosing liquid it is possible, though less easy, to draw up the sample into a capillary filled with air, as was done by Hargitay, Kuhn and Wirz. The method cannot be used with fluids (e.g. bull semen) which are so opaque as to obscure the ice crystals, but it is quite practicable with fluids such as milk which are opaque by ordinary standards. Potts(11) has shown that it is possible to isolate single sea urchin eggs in liquid paraffin and to determine the freezing-point depression of their contents.

ACKNOWLEDGEMENTS

We wish gratefully to acknowledge the co-operation of Messrs P. C. Croghan and T. D. Iles to whom are due certain improvements upon the original procedure.

REFERENCES

(1) Drucker, C., and Schreiner, E. *Biol. Zbl.*, **33**, p. 99 (1913).

(2) Fritsche, H. *Int. Rev. Hydrobiol.*, **8**, p. 22 (1916).

(3) Mosebach, G. *Ber. Deutsch Bot. Gesell.*, **58**, p. 29 (1940).

(4) Jones, L. L. *J. Cell. Comp. Physiol.*, **18**, p. 79 (1941).

(5) Ramsay, J. A. *J. Exp. Biol.*, **26**, p. 57 (1949).

(6) Hargitay, B., Kuhn, W., and Wirz, H. *Experientia*, **7**, p. 276 (1951).

(7) Kinne, O. *Veröff. Inst. Meeresforsch. Bremerhaven*, **1**, p. 47 (1952).

(8) Zwicky, K. T. *Z. Vergl. Physiol.*, **36**, p. 367 (1954).

(9) Scatchard, G., and Prentiss, S. S. *J. Amer. Chem. Soc.*, **55**, p. 4355 (1933).

(10) Beament, J. W. L. *J. Exp. Biol.*, **32**, p. 514 (1955), and personal communication.

(11) Potts, W. T. W. *Nature* [*London*], **169**, p. 834 (1952).

A furnace for obtaining optical spectra of radioactive elements

By L. F. H. Bovey, B.A., Ph.D., A.Inst.P., Chemistry Division, Atomic Energy Research Establishment, Harwell, Berks.

[*Paper first received* 29 *April, and in final form* 19 *May*, 1955]

The construction and operation of a King-type furnace(1) for exciting spectra of radioactive or toxic materials are described. Absorption spectra of scandium, yttrium, and lanthanum have been taken. Both emission and absorption spectra of uranium and plutonium have been observed within the range 2400–7000 Å, in the second order of a 3 m grating spectrograph.

In a series of papers, 1913–1948, King(1) has given the spectra of elements (particularly the rare earths) obtained in emission from a furnace operated at temperatures of about 2500° C. Absorption work using similar furnaces has also been described (e.g. Paul,(2) Bovey and Garton(3)). The results from these experiments have proved very useful for the term analysis of the elements since they give a means of classification of the lines into groups. For such elements as uranium and plutonium, the spectra obtained by arcing and sparking are extremely complex and it is often difficult to distinguish the individual lines from the background. It was thought that the furnace emission spectrum would be much less complex and that the much narrower line width would make wavelength measurement more precise. A furnace was therefore designed in which radioactive elements could be safely heated and the emission and absorption spectra obtained. Soon after this work was begun, Conway(4) described a furnace for taking the emission spectrum of plutonium. Since the present furnace was designed to take absorption spectra in addition to emission spectra, the work was continued.

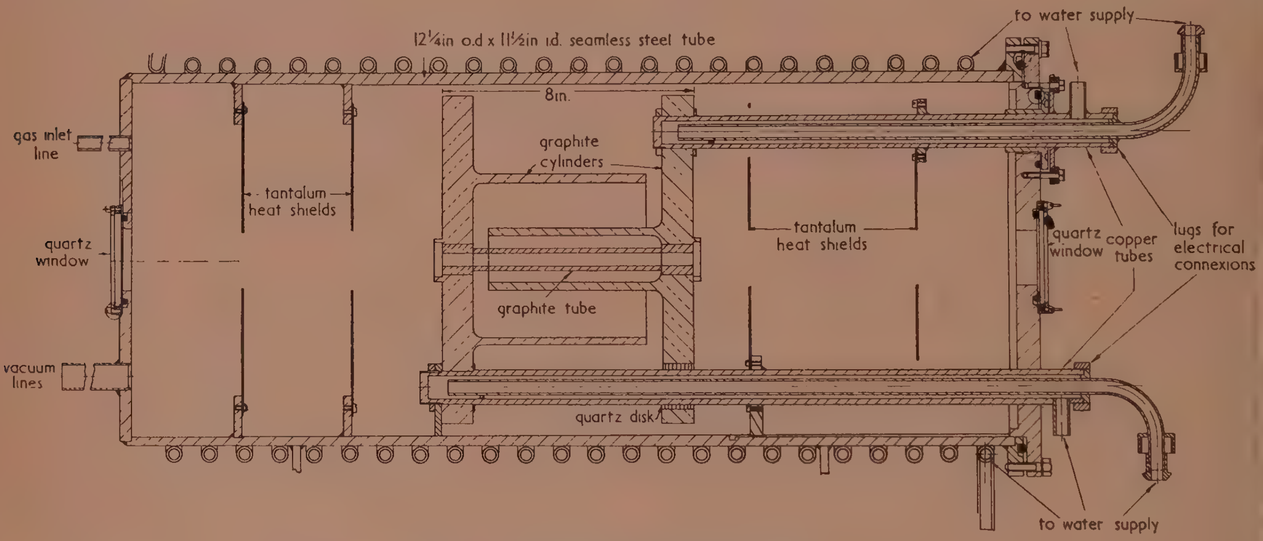


Fig. 1. Diagrammatic view of furnace

DESIGN OF FURNACE

The essential part of a King furnace is a carbon tube which is heated by the passage of large currents (of the order of 1000 A) through it. This tube lies within the walls of the furnace and must be replaced often. In the design followed, it was arranged that the tube and its mount could be withdrawn from the furnace so that replacement was relatively simple. Emission spectra can be produced by a short length of tube (say 3 in.). The power requirements are therefore less in this case than when the longer tubes (to give increase pathlengths) are used for absorption work. In the preser series of experiments where the maximum power available wa some 17 kW, the actual heated tube length of 6 in. was compromise between the requirement of a high temperatu and a long path. When temperatures above 2500° C we used there was, in any case, a rapid disintegration of th carbon tubes and tantalum liners (melting point 3000° C).

The basic design is shown in Fig. 1. A 12 in. diamete (wall thickness $\frac{3}{8}$ in.) mild steel tube, 28 in. long, was close at one end by a steel plate carrying two tubes (one of 1 i diameter leading to a vacuum pump and the other of $\frac{1}{2}$ i diameter leading to a helium gas supply). In the centre the plate, grooves carried O-rings for holding a 3 in. diamet quartz optical disk. Another steel plate at the other e carried hollow water-cooled copper tubes which held t central graphite cylinders and also carried the current to t carbon tube. These tubes were bored from solid copper r so that no soldering was necessary at their "furnace" en They were mounted on the plate with the aid of O-rings that vacuum-tight seals were obtained. In the centre of t plate another 3 in. diameter quartz disk could be placed.

The 8 in. long graphite tube was held by the two graphi cylinders which also acted as heat shields. In order improve the shielding, tantalum sheets were spot welded in cylinders of the same diameter and mounted on the graphi Along the furnace four further sheets of tantalum were us for heat shielding. The concentric heat shields raised t temperature of the tube for the same power input by abo 150° C at 2300° C.

The end plate (carrying the copper tubes and the graph cylinders) was mounted on a set of rails and could be eas withdrawn from the furnace. Replacement of the tube was therefore reasonably simple since the operation could be done outside the tube and be observed. A large O-ring near the circumference of the plate enabled a vacuum seal to be made and bolts were provided to hold the plate in position until the pump had begun to operate.

The vacuum pipe was attached to an Edwards 1S/50 pump through a metal valve. A 0–10 cm gauge and a Pirani gauge were included. The air inlet tube passed through a metal valve to a charcoal trap for the purification of a rare gas.

The furnace and the rails were mounted on a sheet of aluminium alloy (Dural) which formed the base for a box enclosing them. Four of the sides of the box were of Perspex (with the end panels carrying quartz disks) so that all operations within could be observed. The front panel was itted with three sets of the standard rubber glove assemblies (incorporating surgeon's rubber gloves) so that the furnace could be adjusted and loaded without the hands coming into contact with it or any material. A larger hole in the back panel, normally closed by a polyvinyl chloride bag, was cut to allow the addition or removal of auxiliary equipment. The operation of this "dry" box—in particular the addition or removal of any equipment—followed standard procedure used in the handling of radioactive material and will not be urther discussed. It will perhaps be realized how essential the procedure for remote handling was when it is known that the maximum amount of plutonium metal that can be tolerated during a lifetime is 0·6 μg.

Lugs on the dry box were connected to the secondary of a ow voltage high amperage transformer (of 20 kW capacity) and the current controlled by a set of three No. 50 Variacs (ganged in parallel) in the primary circuit. The actual connexions to the furnace were 1 in. square copper bars bolted to both the lugs and the ends of the copper rods so that they could be removed when the furnace was opened.

The box was mounted on a trolley with the pump and the gas inlet line placed underneath on a shelf. Suitable demountable connexions through the box walls were made in the vacuum and gas lines. The pump was on anti-vibration mountings and a length of flexible metal tubing connected it to the vacuum line. The outlet of the pump was attached through a filter to the exhaust extract system of the building.

Cooling water was passed around the outside of the urnace and through the copper tubes. The flow of 5 l./min was the maximum allowed by laboratory regulations but was ufficient to prevent overheating.

OPERATIONAL DETAILS

It had been planned to use the furnace with either a 21 ft rating instrument (Gillieson(5)) or the Hilger 10 ft compact pectrograph. The latter was used in this investigation and he furnace trolley was clamped to an optical bar fixed to he grating mount. For the absorption work the source was ocused so that an image was formed in the middle of the urnace. This image was focused on the slit by a second uartz lens which was inside the dry box. Both lenses and he source were mounted on optical bars so that they could e easily refocused for work in the ultra-violet region.

The optical system was arranged so that an iron arc could e set on the common optical axis of the furnace and grating. n this way it was hoped that the modes of illumination of he grating by both the furnace and the arc were similar, and hat therefore there would be no displacement between the pectra. The iron arc was superimposed on the middle of he emission or absorption spectra.

Three sources were used. For work in the region 4000–6000 Å an over-run 12 V, 48 W car headlight bulb was found satisfactory. At longer wavelengths a carbon arc, and in the ultra-violet region a Siemens high-pressure argon arc (type E.1), gave convenient exposure times. Absorption experi-

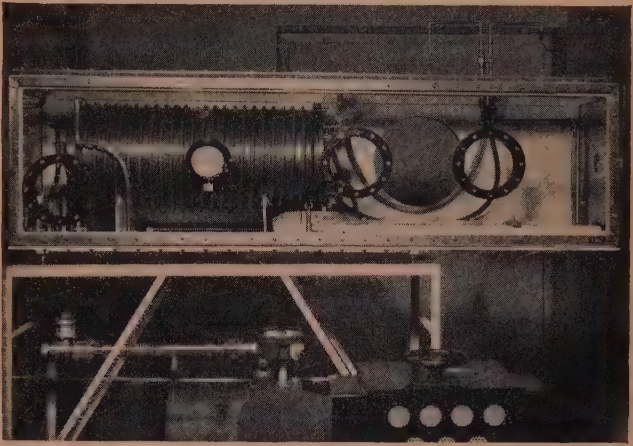


Fig. 2. General view of furnace, box, pumping system and Variac control

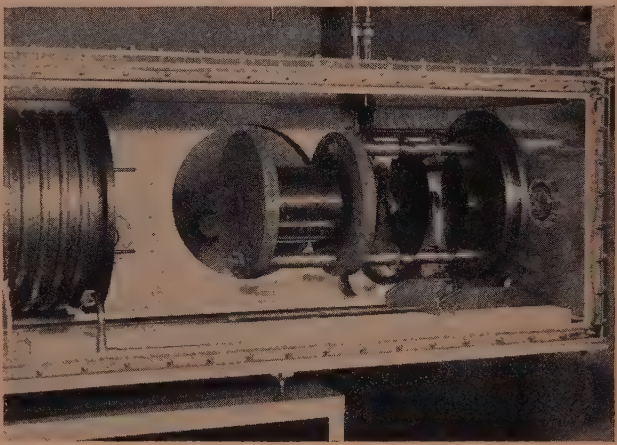


Fig. 3. View of tube holder, heat shields and copper tubes for carrying current

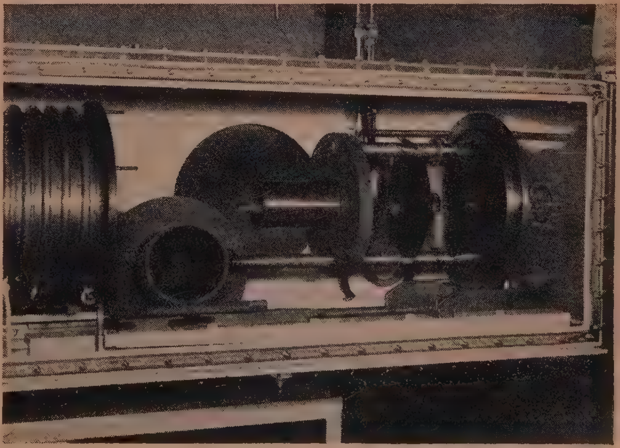


Fig. 4. View of tube holder partially dismantled

ments involved exposures of the order of 30 s and a reasonable number of emission lines were given in times of a few minutes.

By means of a mirror in the optical path, the spectrum could occasionally, in the course of an exposure, be examined through a low dispersion constant deviation spectroscope (Hilger type D. 186) to see if the element was still present.

Fig. 2 shows a general view of the furnace and box. The three positions for the gloves and the hole in the back are clearly seen. The gauge on the front indicates the internal pressure which is kept slightly below atmospheric pressure. The Variac case lies in the foreground. The detailed construction of the interior of the furnace is evident from the Figs. 3 and 4. The former shows the combined graphite holder and heat shield held in position by the copper tubes, themselves supported on the end plate. The latter is the same view with the shielding partially dismounted so that the carbon tube is seen.

EXPERIMENTAL

It had been been found by Bovey and Garton(6) that uranium attacked the walls of a graphite tube very quickly and therefore it was decided to follow the practice of Conway and use a tantalum liner. At first, $\frac{1}{2}$ in. tubes were made from tantalum sheet by rolling and spot welding the overlapping ends. Although these enabled some spectra of uranium to be taken, they were not suitable for long exposures (say five minutes) since they quickly disintegrated. Sintered seamless tubes of tantalum ($\frac{1}{4}$ in. diameter and wall thickness 0·02 in.) lasted for periods of about an hour actual running time. A wall thickness of $\frac{1}{16}$ in. for the graphite tube gave temperatures of about 2400° C. The resistance of the tantalum tube varied with time (presumably because the metal was converted into the carbide) and this change affected the temperature *versus* power input calibration graphs. These temperatures were measured in a preliminary series of experiments by a Hartmann and Brown pyrometer focused on a carbon plug in the centre of the tube.

In experiments when the furnace was being tested, graphite tubes (without lines) of $\frac{3}{4}$ in. outer diameter and $\frac{1}{8}$ in. wall thickness gave temperatures of 2500° C for a power input of 12 kW.

The operation of the furnace was conducted as follows for plutonium. When it was necessary to renew a burnt-out tube, air was let into the system and after the copper bars had been removed the movable plate drawn out into the dry-box where it could be clamped. The operator, wearing rubber gloves, placed his hands in the pair of fixed gloves and transferred the broken tube from the graphite holder to a cellophane bag. A new tube (from a supply already in the box) was inserted and the system pushed into the furnace again and the electrical connexions remade. The furnace was evacuated to about $50\,\mu$ of mercury pressure and current passed to get the tube and holder hot so that the graphite was outgassed as much as possible. The furnace was allowed to cool with the pump running. A fresh charge of plutonium was introduced by first loading it into a nickel spoon attached to a long rod. This spoon was passed through the central hole of the plate (normally covered by the quartz disk) into the centre of the tube where the plutonium filings were shaken out.

After the furnace had been again evacuated, the metal valve to the pump was closed. The tube was heated and the series of spectra taken until either the charge had been exhausted or the tube had disintegrated.

The rare gas supply had been added since it had been feared that the plutonium might not stay long enough in t tube to produce spectra. A preliminary experiment wi uranium and pure helium at 10 cm of mercury pressure h failed to show any increase in the intensity of the spect Since reasonable spectra were obtained with plutonium wh the furnace pressure was a few millimetres of mercury (d to outgassing), experiments with a rare gas were not tried.

RESULTS

Emission and absorption spectra of plutonium are sho in Fig. 5(b). The arc and emission spectra of uranium a compared in Fig. 5(a) and the smaller number of the lines the latter can be noted. In preliminary runs, the absorpti

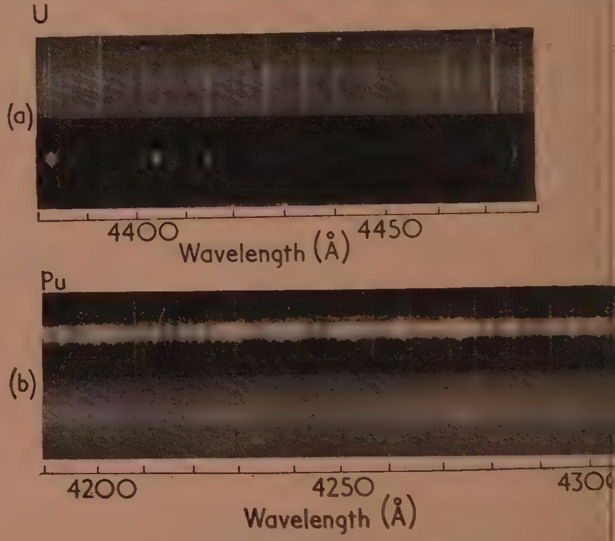


Fig. 5(a). Arc and furnace emission spectra of uraniu

Fig. 5(b). Emission and absorption spectra of plutoniu

Iron arc calibration spectra are superimposed on the last thre
Not all the lines shown are uranium or plutonium.

spectra of scandium, yttrium and lanthanum were taken, a these, together with the absorption and emission spectra uranium and plutonium, are now being examined measured. Results will be reported in due course.

ACKNOWLEDGEMENTS

The basic idea was suggested by Mr. W. R. S. Garton Imperial College who has always been pleased to give adv

The furnace was built by the Western Detail Co. Ltd., the author would like to thank Mr. Gardiner of that f for many practical suggestions.

The author is also indebted to Dr. A. H. Gillieson constant encouragement, to Mr. H. S. Wise for much exp mental assistance and to the staff of the Engineering W shops who have always been most co-operative.

REFERENCES

(1) King, A. S. *Trans Electrochem. Soc.*, **89**, p. 301 (19
(2) Paul, F. W. *Phys. Rev.*, **49**, p. 156 (1936).
(3) Bovey, L. F. H., and Garton, W. R. S. *Proc. P Soc.* [*London*], **57**, p. 291 (1954).
(4) Conway, J. G. *J. Opt. Soc. Amer.*, **44**, p. 276 (1954).
(5) Gillieson, A. H. C. P. *J. Sci. Instrum.*, **26**, p. 335 (19
(6) Bovey, L. F. H., and Garton, W. R. S. Unpublis work (1953).

An apparatus for the measurement of γ-radiation from the human body*

By J. RUNDO, B.Sc., A.R.C.S., A.R.I.C.,† Finsen Laboratory, Copenhagen Ø, Denmark

[*Paper first received* 24 *May, and in final form* 4 *July*, 1955]

The design and construction of a total-body γ-monitor are described. It employs four long, high-pressure ionization chambers connected differentially with four similar chambers to reduce the background intensity. The chambers are mounted in a water-filled steel tank, to provide shielding against local γ-radiation. The differential current develops a potential across a stable high-value resistor, and this potential is amplified by a vibrating reed electrometer. The amplified output is displayed on an electromechanical recorder and the mean out-of-balance current is determined automatically. The errors are such that a two-hour measurement of body radioactivity enables the potassium content of a subject to be determined with a probable error of about 17% under ideal conditions.

'or some years interest has centred on the measurement of adioactivity in the human body. The efforts expended have een directed towards measuring the natural radioactivity of e body and to devising techniques for the early detection f increase in this natural radioactivity in the cases of workers ith radioactive isotopes. The methods which have been mployed are summarized in Table 1.

'able 1. *Methods and sensitivities of determination of body-radioactivity*

nvestigators	*Principle*	*Lower limit of detectable radioactivity (μg of radium*)*
vans(1)	Single Geiger–Müller tube	10^{-1}
less and McNiff(2)	Single ionization chamber	$1{\cdot}5 \times 10^{-2}$
ievert(3)	10 ionization chambers	2×10^{-3} (6–8 observations)
urch and Spiers(4)	Balanced ionization chamber system	2×10^{-3} (Single 2 h observation)
eines and others(5)	Organic scintillator with 45 photo-multipliers	10^{-3} (Single short observation)
uthor	Balanced ionization chamber system	2×10^{-3} (Single 2 h observation)

* In equilibrium with its decay products.

The apparatus described here is similar to that of Burch nd Spiers(4); it was designed at the Atomic Energy Research stablishment, Harwell, and installed at the Central aboratory of the Finsen Institute, Copenhagen, for the tudy of patients contaminated with thorium. Since the inimum body-burden of these patients is in the region of g of thorium (about $0{\cdot}1\ \mu$C), high sensitivity was not a rimary requirement, but the apparatus has shown itself apable of measuring radioactivity of the same order of agnitude as that from the naturally occurring ^{40}K in the uman body. It also has other applications in isotope tudies, such as the measurement of biological half-life, for hich it is very convenient. The usual method is based on xcretion studies and the incomplete collection of excreta ay introduce considerable inaccuracy.

DESIGN AND CONSTRUCTION

On the grounds of cheapness and reliability, high-pressure ionization chambers were chosen as the detector, although a theoretical study(6) has shown that a complicated system of Geiger–Müller tubes working in anti-coincidence, or a scintillation counter, should give a better performance. The work of Reines and others(5) has borne out the latter suggestion (see Table 1).

The problems of the spatial distribution and number of the ionization chambers have been discussed elsewhere.(3, 4, 7, 8) The author used four ionization chambers placed above the person to be measured, with four similar chambers connected differentially with them, and separated from them by 60 cm of water shielding, to reduce the background current.

The ionization chambers used are similar to those described by Taylor and Sharpe(9) but are much longer, the active length being 6 ft (183 cm). In addition, to reduce the effects of α-particles from radioactive contamination in the constructional materials, the collector electrodes are made of $\frac{1}{4}$ in. diameter rods. The filling gas is argon at 20 atmospheres pressure, the active volume being 38 litres.

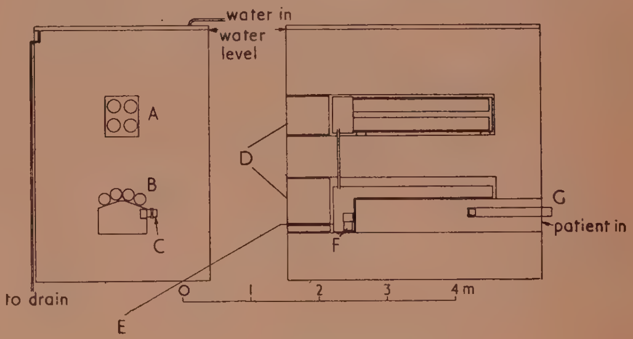


Fig. 1. Layout of apparatus

A, four backing chambers; *B*, four measuring chambers; *C*, extractor fan; *D*, small shielding tanks, removable for access to chambers; *E*, connecting cables to vibrating reed electrometer, indicating unit, h.t. batteries, etc.; *F*, input resistors, range switch, vibrating reed and head amplifier; *G*, ventilating shaft.

The differential current from the chambers develops a potential across a stable high-value resistor (in the range 10^8 to $10^{12}\ \Omega$), and this potential is measured with a vibrating reed electrometer (A.E.R.E. type 1086A). The output of this is fed to a Kent Multelec electromechanical recorder with centre zero, coupled to which is an automatic averaging device.

---

* Presented, in part, at the 7th International Congress of adiology, Copenhagen, 1953.

† Now at Atomic Energy Research Establishment, Harwell, erks.

The ionization chambers, input resistors, vibrating reed and head amplifier are built into a steel tank 378 cm × 253 cm × 372 cm tall. The sides and bottom are built up from 4 ft square plates of the type commonly used for "static" water tanks, the ends being separately fabricated. The tank is made water-tight by covering all joint surfaces with bituminous jointing compound during assembly. The lay-out of the apparatus is shown in Fig. 1.

The four measuring chambers are placed in a metal rack so that they are 40 cm from the centre line of the stretcher, the backing chambers being mounted as two pairs in a metal frame above the measuring chambers. The ends of the chambers are accessible for maintenance purposes by removing the two small shielding tanks, which are normally filled with water. In this way there is a minimum of 60 cm water shielding on all sides and there is no background absorption effect, as studied with a 70 kg water phantom.

REDUCTION OF "BACKGROUND"

Because of the different shielding, the background currents in the backing and measuring chambers are not equal. When the apparatus was first taken into use typical figures were $-1{\cdot}48 \times 10^{-12}$ A and $+1{\cdot}19 \times 10^{-12}$ A respectively, the difference current being $-2{\cdot}9 \times 10^{-13}$ A. (The convention adopted for the signs of the currents has been to call that in the measuring chambers positive.) The absolute magnitude and sign of this current are immaterial, but for convenience it was reduced in magnitude (and made positive) by increasing the current in the measuring chambers with a small source of uranyl nitrate, placed near to these chambers. The out-of-balance current then became about $+4 \times 10^{-14}$ A but is dependent on the height of the water shielding in the tank and on the barometric pressure. Variations in the former were eliminated by fitting an overflow pipe and allowing water to run continuously but slowly into the tank. The effect of varying atmospheric pressure on cosmic-ray intensity is well known, but with most ionization chambers the changes of atmospheric pressure normally encountered cause the background current to change by about 1%. In the present case a 1% change in the background current of the backing chambers is not accompanied by a 1% change in the background current of the measuring chambers, because of the water shielding between them.

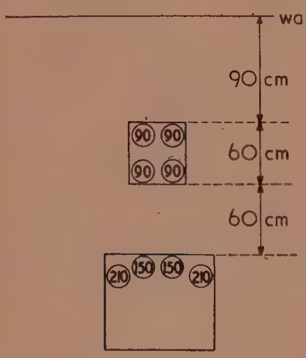


Fig. 2. Diagramatic representation of the ion-chambers in vertical cross-section. The figures in the circles give the amounts of water shielding in the vertical plane for each chamber. The small shielding effect of the chambers themselves is ignored

The behaviour of the differential background current with varying atmospheric pressure can be predicted in the follo ing manner. Assume that at sea-level after the first 1000 of water equivalent of atmosphere (980 mb), the lin absorption coefficient for cosmic radiation in water 0·01 cm^{-1}. Consider two similar sets of ionization chamb arranged one above the other, as shown in Fig. 2. Let ionization current due to cosmic radiation in each chamb when unshielded be I, and let the shielded currents in upper and lower sets be I_u and I_l. Assuming that direction of cosmic radiation is within a small angle to vertical, we have:

$$I_u = 4I \exp[-0{\cdot}01(B_w - 910)]$$

and

$$I_l = 2I \exp[-0{\cdot}01(B_w - 850)] + \exp[-0{\cdot}01(B_w - 790)]$$

where B_w is the atmospheric pressure in centimetres of wat

If I_l is increased by a small source producing a curren the difference current becomes:

$$I_l' - I_u = \Delta I = i + 2I\{\exp[-0{\cdot}01(1{\cdot}0201B - 850)] + \exp[-0{\cdot}01(1{\cdot}0201B - 790)] - 2\exp[-0{\cdot}01(1{\cdot}0201B - 910)]\}$$

where B is the atmospheric pressure in millibars (1000 mb 750·1 mm of mercury at 0° C and 45° latitude). In equati (2) i allows for the constant current in the measuring (low chambers due to the uranium source, and for the differen current due to local γ-radiation in both sets of chambers

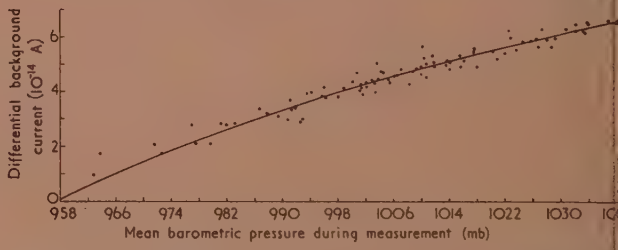


Fig. 3. The differential background current plotted as a function of the barometric pressure. The smooth curve represents the predicted behaviour with the constants adjusted to fit the experimental data

ΔI is plotted as a function of B in Fig. 3 with values and I adjusted to fit the experimental observations. T smooth curve is seen to fit the data very well, but there slightly greater scatter than would be expected on pur statistical grounds. This is a reflexion of systematic err in the vibrating reed electrometer, and of variations cosmic-ray intensity not associated with changes in atm spheric pressure.

DETERMINATION OF THE MEAN DIFFERENTIA CURRENT

The Kent Multelec recorder "samples" the output of vibrating reed electrometer at intervals of 33⅓ s, and recorded values of the differential voltage form a Gaussi distribution about the mean as shown in Fig. 4. Because the occurrence of cosmic-ray "stars" and dense extens "showers" in one set of chambers predominantly there is eater number of events outside three standard deviations om the mean than predicted by the equation for the aussian error curve. The number of these anomalous events ccurring in the backing chambers is greater than the number ccurring in the measuring chambers; this is undoubtedly a nction of the better screening of the measuring chambers, id of the geometrical arrangements of both sets.

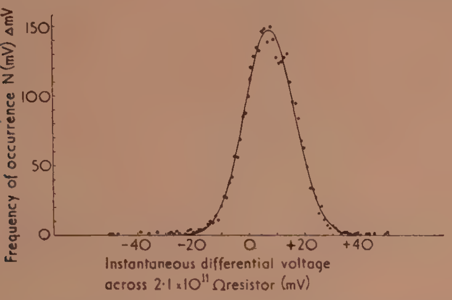


Fig. 4. Histogram of thirty-one hours' record of differential background current. Smooth curve represents Gaussian error curve. 26 observations were outside -3σ and 12 were outside $+3\sigma$ (4·5 for Gaussian distribution)

The determination of the mean differential current from he recorded values is a very tedious procedure, and an veraging device has been constructed to carry out this etermination automatically. Two extra slide-wire potentioneters are mounted on the axle of the Kent recorder and are onnected so that a current proportional to the deflexion of he recorder passes through a milliampere-hour meter. The ircuit is shown in Fig. 5; a direct current of about 0·2 A is tabilized by an iron-in-hydrogen "barretter" V_2 and flows hrough a limiting resistor, relay $B/3$ (suitably by-passed) and RV_3. When relay $A/2$ is operated, and the key is in the "on" osition, the current flowing in the milliampere-hour meter aries linearly from 0 to 10 mA as the recorder deflexion hanges from negative to positive full-scale, RV_4 acting as a ompensator.

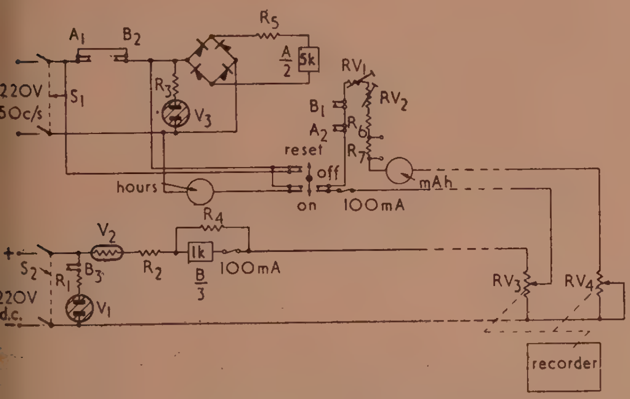


Fig. 5. Circuit of automatic averaging device

$R_1 = 0{\cdot}5\ \mathrm{M\Omega}$
$R_2 = 540\ \Omega,\ 25\ \mathrm{W}$
$R_3 = 0{\cdot}5\ \mathrm{M\Omega}$
$R_4 = 150\ \Omega,\ 5\ \mathrm{W}$
$R_5 = 33\ \mathrm{k\Omega},\ 2\ \mathrm{W}$
$R_6 = 400\ \Omega$
$R_7 = 1\ \Omega,\ 1\%$

$RV_1 = 10\ \Omega$
$RV_2 = 100\ \Omega$
$RV_3, RV_4 = 35\ \Omega$

V_1 = CV 988
V_2 = Osram EU XIV
V_3 = CV 988

An hour-meter records the time of measurement, the a.c. supply being quartz-crystal controlled at 50 c/s. Failure of either a.c. or d.c. supplies stops the averaging process and the timer, and averaging does not start again on the reappearance of power, until the apparatus is manually reset. RV_2 and RV_1 form coarse and fine controls for adjusting the current in the milliampere-hour meter; the sockets across R_7 are for connexion to a suitable galvanometer as an aid in setting-up the device. Calibration is conveniently checked by short-circuiting the input to the recorder, switching it off and timing the number of revolutions of the armature of the milliampere-hour meter in 5 or 10 min. The overall linearity is theoretically perfect, but, in practice, deviations from linearity can be expected due to non-linearity in the windings of the two potentiometers, RV_3 and RV_4, and in the response of the milliampere-hour meter. In any case, it is not possible to adjust the recorder deflexion to much better than the equivalent of 0·01 mA in the milliampere-hour meter, when carrying out the calibration. The most serious departures from linearity are in the current range 0 to 3·5 mA; over the rest of the range the linearity is better than 1%. The deviations are not serious as the recorder only rarely makes excursions into the non-linear region, even when the apparatus is working on its most sensitive range.

Before relying on the value of the mean as determined by the averager, the mean in all measurements made with the apparatus was determined by analysis of the recorded values, over a period of three months. The difference between the two values was rarely greater than the statistical error, and almost always much less. Some typical figures are shown in Table 2. It is found that the agreement between the two values is poorest for measurements made at low sensitivity, where the spread of the points on the chart is small.

Table 2. *Accuracy of automatic averaging device*

Approximate spread of points on chart (*% of f.s.d.*)	*Mean from averager* (mV)	*Mean from chart* (mV)
4	184·0 ± 0·9	182·2 ± 1·6
10	161·0 ± 0·6	161·6 ± 1·1
14	606·5 ± 1·8	606·8 ± 2·8
27	220·7 ± 2·4	220·0 ± 3·7
90	48·97 ± 0·69	48·89 ± 1·04

This is because the mean may fall at or near a point where the linearity of the averager is poor. Often allowance can be made for this.

ERRORS

In an apparatus designed for the measurements of low levels of radioactivity the problem of errors plays an important role in limiting the sensitivity. Burch⁽¹⁰⁾ has shown that in a system of this type the spread of statistical variations is characterized by an "effective time constant" defined by the relation

$$\tau_{eff} = \sqrt{\Sigma\tau^2} \qquad (3)$$

where the independent time constants τ are (*a*) that involved by the mobility of heavy ions in the chambers; (*b*) the *RC* time constant of the input circuit to the vibrating reed electrometer; and (*c*) that of the recorder. It is found that, within experimental error, the current fluctuations are of the same magnitude as would be observed under rate-of-drift conditions, at intervals of τ_{eff}. It follows that when a measurement by the rate-of-drift technique is made for a period T, the standard error, $\sigma(T)$, is given by

$$\sigma(T) = \sigma\sqrt{(\tau_{eff}/T)} \tag{4}$$

where σ is the standard deviation of a single point, by analogy with the standard error of the number of counts observed with a scaler. This represents the minimum attainable value of the error.

When we use the grid-resistor technique to measure the differential current, and record "sample" values of the current at intervals of t seconds ($33\frac{1}{3}$ s for the Kent Multelec recorder) information is lost, and the standard error of the mean, determined from the record, is higher than the minimum attainable value $\sigma(T)$, by a factor

$$\sqrt{\left(\frac{\tau_{eff}+t}{\tau_{eff}}\right)} \tag{5}$$

Thus the standard error becomes

$$\sigma(T, t) = \sigma\sqrt{\left(\frac{\tau_{eff}}{T}\cdot\frac{\tau_{eff}+t}{\tau_{eff}}\right)}$$

$$= \sigma\sqrt{\left(\frac{\tau_{eff}+t}{T}\right)} \tag{6}$$

The standard error of the mean as determined by the automatic averaging device is the minimum attainable value, since $t = 0$ and no information is lost.

These results may be compared with those obtained in the statistical analysis of the counting-rate meter as first developed by Schiff and Evans,(11) and modified by Burgess,(12) it being remembered that counting-rate meter theory only gives the lower limit of the errors in ionization chambers, because of the different effects of ionizing particles with different specific ionizations.

Application of the above equation to the practical case yields the following results. With 90 V on each set of chambers, $\tau_{eff} = 15{\cdot}0$ s for the $2{\cdot}1 \times 10^{11}\,\Omega$ resistor and $\sigma = \pm(4{\cdot}00 \pm 0{\cdot}09) \times 10^{-14}$ A. Hence for a two-hour measurement

$$\sigma(T, t) = \pm 4{\cdot}00\sqrt{\left(\frac{15{\cdot}0 + 33{\cdot}3}{7200}\right)} \times 10^{-14}$$

$$= \pm 0{\cdot}32 \times 10^{-14}\ \text{A} \tag{7}$$

when the mean is determined from the recorded values on the chart, and the anomalous values are ignored. The automatic averaging device cannot "ignore" the anomalous events and σ is therefore a little higher than above, namely, $\pm(4{\cdot}50 \pm 0{\cdot}10) \times 10^{-14}$ A. Hence, for a two-hour measurement

$$\sigma(T) = \pm 4{\cdot}50\sqrt{\frac{15{\cdot}0}{7200}} \times 10^{-14}$$

$$= \pm 0{\cdot}20 \times 10^{-14}\ \text{A} \tag{8}$$

Thus, even with the higher standard deviation the standard error is some 60% of that obtainable by the tedious procedure of analysis of the printed record.

PERFORMANCE AND SENSITIVITY

The "geometry" of the patient tunnel was investigated with the aid of a "point" source of thorium; Fig. 6 shows the response of the apparatus when the source was moved along the axis of the tunnel at three different heights. For comparison the positions of the measuring chambers (upp shaded strip) and the stretcher (lower shaded strip) a shown, and the position occupied by a patient is indicate Ignoring differences in sensitivity due to the different ene gies of the γ-quanta emitted, it is clear that activity deposit in the extremities (e.g. ^{131}I in the thyroid) will be measur with a lower efficiency than the same amount of activity d posited in the abdominal region (e.g. ^{198}Au in the stomach However, for the majority of the measurements on patien with internally deposited thorium slight variations in t longitudinal positions of the patients on the stretcher are little significance because the major parts of the activity a to be found in liver and spleen.

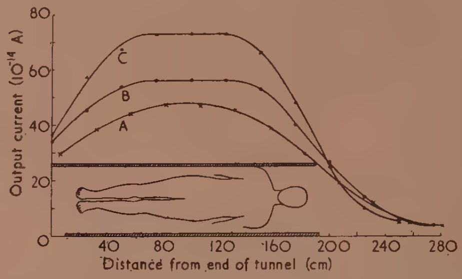


Fig. 6. Response to thorium in different positions along patient tunnel

A, on floor of patient tunnel; *B*, 10 cm above floor (on stretcher); *C*, 25 cm above floor.

The effect of moving the source laterally across the tunn has also been investigated. At 90 cm from the back, whi is under the middle of the measuring chambers, the respon is as shown in Fig. 7. The symmetry of the curves shows th the four chambers are working with equal efficiency; it also seen that while the curves made at floor level and on t stretcher are comparatively flat, that at 25 cm above flo level shows a fairly pronounced peak. At this height t

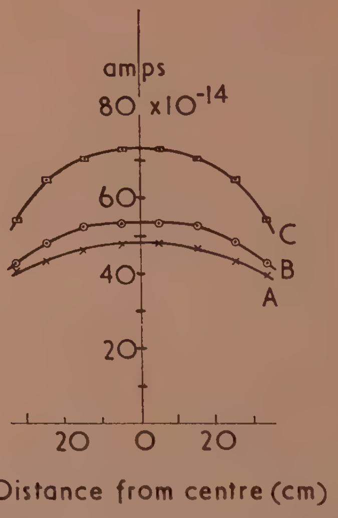


Fig. 7. Response to thorium across the patient tunnel, 90 cm from the back

A, on floor of patient tunnel; *B*, 10 cm above floor (on stretcher); *C*, 25 cm above floor.

response 25 cm from the centre line is 87% of that at the centre. This disadvantage has to be tolerated in this design.

As an aid in studying the response of the apparatus to an isotope distributed throughout the human body, the ratio

$$\frac{\text{Response to line source}}{\text{Response to point source of same activity}}$$

has been measured for lines of different lengths using a few microcuries of ^{42}K. The results are shown in Fig. 8 and

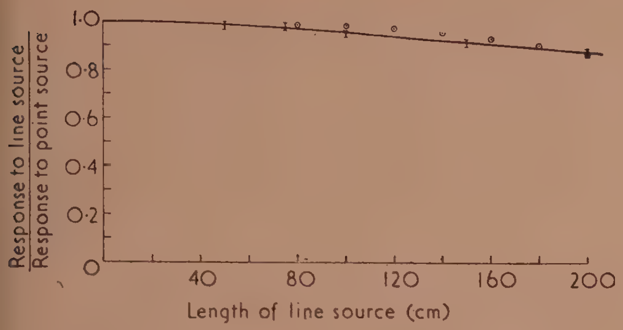


Fig. 8. Response of apparatus to extended sources of different lengths

I = experimental, ^{42}K, 1·51 MeV γ; ⊙ = graphical integration of curve *B* of Fig. 6, thorium source, 2·62 MeV γ.

may be compared with the calculated values of the ratio obtained by graphical integration of curve *B* of Fig. 6.

The specific response of the apparatus varies with the energy of the γ-quanta being measured, and the results for some relevant isotopes are given in Table 3.

Table 3. *Sensitivity of the apparatus to different isotopes*

Isotope	*Specific response* 10^{-14} *A/μc on the stretcher*	*k factor, mr/h at 1 cm from 1μc in air*	*Standard error for 2-hour measurement* (μc)
^{42}K	14·5	1·55	0·014
^{131}I	22·4	2·29	0·010
^{232}Th + decay products	119·6 (*a*)	≃ 14·5 (*b*)	0·002
^{226}Ra + decay products	93·4	9·1 (*c*)	0·002
^{59}Fe	65·3	6·55	0·003
^{40}K	0·77 (*d*)	—	30 (*e*)

(*a*) Calculated from response to thorium of known "age."
(*b*) Calculated from γ-energies available and represents an "upper limit."
(*c*) Dose rate from radium shielded by 0·5 mm Monel metal.
(*d*) Current per 100 g potassium.
(*e*) g potassium.

As a test of the linearity of response up to about 10^{-11} A, the decay of a source of ^{32}P (initially about 4 mc), measured by its *bremsstrahlung* was studied. The initial current was 7×10^{-12} A and the decay, which was accurately exponential, was followed for about seven half-lives. A least-squares treatment of the results yielded the value of 14·45 ± 0·03 days for the half-life in good agreement with previously published values.(13,14) The standard error of ±0·03 days includes both statistical and systematic errors.

RESPONSE TO HUMANS

Some results obtained from the measurements of patients with internally-deposited thorium have been published elsewhere.(15) Shortly after these measurements were started, it was observed that the differential background current was increased immediately after a measurement, by as much as $1\cdot0 \times 10^{-14}$ A. It was found that the thoron in the exhaled breath of the patient decayed in the tunnel, the solid daughter products attaching themselves to the metal lining of the tunnel, mainly the roof, where they were very close to the ionization chambers. This problem was resolved by fitting an extractor fan and ventilating shaft with an opening on a level with the patient's shoulders. Smoke tests showed that air was removed rapidly from the region round the patient's head, without creating much draught, and no increase in background after measurement of a thorium patient was observed after the installation.

To assess the capabilities of the apparatus in measuring the natural radioactivity of persons unexposed to long-lived γ-emitters, a number of measurements have been made on thirteen females and nine males. The results have been used to derive an estimate for the potassium content of these "control" subjects, ascribing the whole of the response to the ^{40}K isotope, present to the extent of 0·012% in natural potassium. Compared with a "point" source on the stretcher, the response to a human subject containing the same amount of activity will be reduced because of the length of, and the self-absorption in, the body. On the other hand, the source as a whole will be a little nearer to the chambers. A correction can be made for the first of these factors from the curve of Fig. 8. Self-absorption has been studied with the help of the short-lived isotope ^{42}K, the quantum energy of which is almost the same as that of ^{40}K (1·51 and 1·46 MeV respectively). The responses to two or three of the controls were measured frequently in the apparatus after ingestion of about 5 μc of ^{42}K and decay curves were plotted. In each case, after an initial rise, the response fell faster than dictated by the half-life, as the ^{42}K became distributed throughout the body. After about 8–10 hours, the decay had become substantially one of 12·44 hours half-life, and it was assumed that the distribution was then similar to that of the potassium of the body. Nine of the controls of widely differing weights were measured in the apparatus at least ten hours after oral ingestion of about 5 μc of ^{42}K. Comparison with the response to a "point" source of the same initial activity, and correction for decay and for the response to ^{40}K in the body, gave a ratio which was a measure of both self-absorption and length. This was then corrected for length with the aid of Fig. 8, giving a ratio which was purely a function of body-weight (Fig. 9). (It should be noted that the correction for

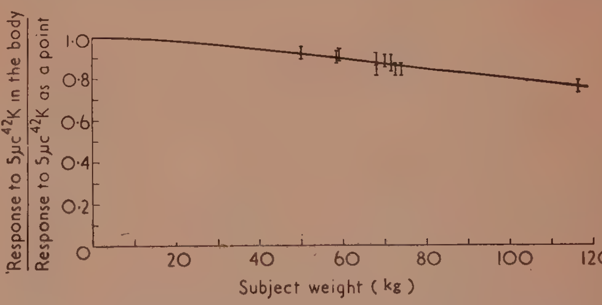


Fig. 9. Absorption effect for ^{42}K in subjects of different weights

length involved the assumption that the activity was distributed uniformly throughout the body.) In this way the potassium contents of the control subjects have been calculated, the results for females indicating $0\cdot17_7 \pm 0\cdot01\%$ and for males $0\cdot20_9 \pm 0\cdot01\%$ of body weight. These results are in good agreement with other measurements of total-body potassium.(4, 16) The difference between the results for males and females is in harmony with measurements of "exchangeable" potassium by the method of isotopic dilution.(17–21)

Assuming a value of $0\cdot21\%$ of body weight, the potassium content of a 70 kg "standard man" is 147 g and from Table 3 it is seen that a two-hour measurement of body radioactivity enables the potassium content to be determined with a standard error of about 25%, or a probable error of some 17%, when allowance is made for self-absorption in, and the length of, the subject. However, uncertainties in the background owing to the effects already discussed, may increase the error in any particular measurement to as much as 30% under unfavourable conditions. The results quoted above are based on several measurements, each of two hours' duration on each subject.

CONCLUSIONS

The apparatus has proved very stable in use over a period of nearly two years, no major faults having developed. With the ionization chamber technique described here it is doubtful if much increase in accuracy can be achieved, but the dependence of the differential background current on changes in cosmic-ray intensity and energy spectrum could be much reduced, if not eliminated, either by reducing the gas pressure in the measuring chambers, or less easily, by increasing the shielding to a value very large compared with the shielding between the two sets of chambers. Practically, this amounts to the solution of building an underground apparatus adopted by Sievert.(22)

A further improvement in design would result from giving the backing chambers the same geometrical arrangement as the measuring chambers, which should substantially reduce the number of "anomalous" events in the differential current.

ACKNOWLEDGEMENTS

A number of people have assisted in the construction of the apparatus; in particular the author wishes to thank Mr. F. Wade of the Atomic Energy Research Establishment who supervised the design of the ionization chambers and shielding tank, and who assisted in the assembly of the apparatus. Thanks are also due to Mr. A. Davidson, erection superintendent of Messrs. Braithwaite and Co. Engineers Ltd., and Mr. S. Kunz for their assistance in the erection of the tank. The author is grateful to Dr. P. R. J. Burch valuable discussion on the subject of errors. This work w carried out by the author while on leave of absence from t Atomic Energy Research Establishment, Harwell.

REFERENCES

(1) Evans, R. D. *Amer. J. Roentgenol.*, **37**, p. 368 (193
(2) Hess, V. F., and McNiff, W. T. *Amer. J. Roentgen* **57**, p. 91 (1947).
(3) Sievert, R. M. *Ark. Fys.*, **3**, p. 337 (1951).
(4) Burch, P. R. J., and Spiers, F. W. *Nature* [*Londo* **172**, p. 519 (1953).
(5) Reines, F., Schuch, R. L., Cowan, C. L., Harris F. B., Anderson, E. C., and Hayes, F. N. *Natu* [*London*], **172**, p. 521 (1953).
(6) Burch, P. R. J. Thesis, University of Leeds (1952).
(7) Spiers, F. W., and Burch, P. R. J. *Biological Haza of Atomic Energy*, pp. 203–13. Ed. A. Hadd (Oxford: University Press, 1952).
(8) Taylor, D., Rundo, J., Jensen, P. G., Henriqu O. M., and Wade, F. *Atomic Energy Resea Establishment Report* El/R 1250 (1953).
(9) Taylor, D., and Sharpe, J. *Proc. Instn Elect. Eng* **98** (II), p. 174 (1951).
(10) Burch, P. R. J. *Proc. Phys. Soc.* [*London*] *A*, **67**, p. 4 (1954).
(11) Schiff, L. I., and Evans, R. D. *Rev. Sci. Instrum.*, p. 456 (1936).
(12) Burgess, R. E. *Rev. Sci. Instrum.*, **20**, p. 964 (1949)
(13) Sinclair, W. K., and Holloway, A. F. *Nat* [*London*], **167**, p. 365 (1951).
(14) Lockett, E. E., and Thomas, R. H. *Nucleonics*, (3), p. 14 (1953).
(15) Rundo, J., and Faber, M. *Rec. Trav. Chim. Pays-B* **74** (5), p. 416 (1955).
(16) Shohl, A. T. *Mineral Metabolism* (New York: Reinh Publishing Corporation, 1939).
(17) Corsa, L., Olney, J. M., Steenburg, R. W., Ba M. R., and Moore, F. D. *J. Clin. Invest.*, **29**, p. 1 (1950).
(18) Aikawa, J. K., Harrell, G. T., and Eisenberg, *J. Clin. Invest.*, **31**, p. 367 (1952).
(19) Edelman, I. S., Olney, J. M., James, A. H., Broo L., and Moore, F. D. *Science*, **115**, p. 447 (1952)
(20) Blainey, J. D., Cooke, W. T., Quinton, A., and Sco K. W. *Clin. Sci.*, **13**, p. 165 (1954).
(21) Rundo, J., and Sagild, U. *Nature* [*London*], **1** p. 774 (1955).
(22) Sievert, R. M. Private communication (1952).

An electronic magnetometer

By B. G. Cragg, M.A., Department of Anatomy, University College, London

[*Paper first received* 14 *February, and in final form* 16 *June*, 1955]

A probe unit containing a miniature cathode-ray tube is brought into the field to be measured, and the resulting deflexion of the electron beam is automatically compensated by a voltage applied to the electrostatic deflecting plates. This voltage is proportional to the magnetic field for steady fields and for fields changing at not more than 10 kc/s. Using standard components an output of 12·5 V/oersted is obtainable with a drift of about 1 mV/min. The smallest field measurable is thus 10^{-4} oersted.

The principle of balancing the magnetic field by a local electrostatic field so that an electron beam is undeflected is similar to that used by Sir. J. J. Thomson* to determine the ratio of charge to mass for the electron. In the apparatus to be described part of the light-spot on the phosphor is hidden by a shutter in front of the screen. A magnetic field deflecting the beam changes the amount of light that passes the shutter and falls on a photomultiplier. The latter is connected to a circuit which applies a correcting voltage to the electrostatic deflecting plates of the tube. This voltage is proportional to the magnetic field and can be read on a meter or displayed on an oscilloscope. The main advantages of this method are that the frequency response extends to 10 kc/s, and that both steady and changing magnetic fields can be measured continuously with 1% accuracy. The disadvantages are that since the cathode-ray tube is 3 cm in diameter only the average field in a considerable volume can be measured, that the cathode-ray tubes at present in use contain magnetic materials which distort the field, and that the probe unit has to contain four electronic tubes and associated components.

The magnetic field H and the electrostatic field E are related by the well-known equation

$$\frac{H}{E}=\frac{L_1}{L_2}\sqrt{\frac{2eV}{m}}$$

where V is the potential difference accelerating the electron beam, and L_1 and L_2 are the lengths of beam over which the electrostatic and the magnetic fields act respectively. The fact that the constant of proportionality between the electric and magnetic fields depends on the lengths of the beam over which the fields act makes it difficult to use the method for absolute measurements, unless the fields are uniform over the length of the electron beam. For non-uniform magnetic fields the deflecting voltage is still proportional to an average of the field taken over the length of the beam, and the constant of proportionality can be obtained by comparison with another method. The equation shows that the constancy of the accelerating voltage across the cathode-ray tube must be considered in designing the magnetometer.

Fig. 1 shows a version of the magnetometer in which the cathode-ray tube, photomultiplier and associated circuits are housed in a probe unit connected by a screened cable to a stabilized power-pack. The cathode-ray tube is sheathed in black paper and held in the horizontal brass tube facing the photomultiplier which is contained in the vertical tube. A metal shutter is fixed on the front of the cathode-ray tube to obscure half the screen, which is thus divided along a diameter parallel to the deflecting plates. The amplifying valves and associated circuits are immediately above the photomultiplier n a box connected to the power-pack by a twelve-way creened cable. The connexions between the box and the base of the cathode-ray tube pass internally through the vertical and horizontal tubes. The output voltage to be measured is obtained at terminals on the power-pack.

Fig. 2 shows the circuit of the stabilized power-pack, light-detector and cathode-ray tube. A 1250 V d.c. supply isolated from earth is obtained in the usual way and taken to the series valve V_1, which provides 40 mA at 1000 V. This supply is split in half by the first triode in V_5 and is also divided into 250 V and 750 V by the second triode, the cathode of which is earthed. The current supplies are thus stabilized at +250, −250, and −750 V with respect to earth.

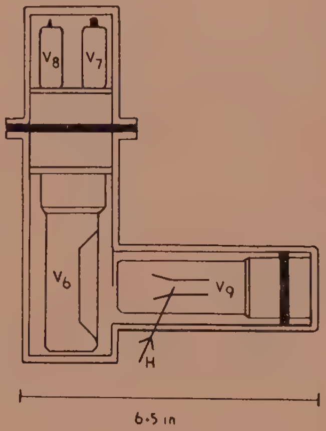


Fig. 1. The construction of the probe-unit of the magnetometer. (For key, see Fig. 2)

The anode of the photomultiplier V_6 is connected to the grid of a low-noise pentode V_7, the anode load of which is the input impedance of the cathode-follower V_8. The cathode load of V_8 is R_{19}, and the voltage between the cathode and earth is applied to the electrostatic deflecting plates of V_9 and to the meter M which has an impedance of not less than 500 Ω/V. The output voltage to be measured is positive or negative about earth according to the polarity of the magnetic field, and is set to zero by the potentiometer R_{15} for zero field or for a small arbitrary field which may be that of the Earth. The switch s_1 is used to centre the light-spot on the screen when the apparatus is first switched on.

The movement of the light-spot on the screen which would be produced by the magnetic field is counteracted by the feedback from the cathode of V_8 to the deflecting plate of V_9. This feedback reduces the sensitivity of the meter reading from 1000 V/oersted to 12·5 V/oersted, and reduces the noise-level and improves the linearity of the response in the same ratio. It is essential to use a cathode-ray tube with a short persistence phosphor since after-glow causes a relaxation oscillation. The condenser C_1 is used to limit the high-frequency response of the amplifier to a value which insures stability.

---

* Thomson, J. J., *Phil. Mag.*, **44**, p. 293 (1897).

Fig. 3 shows the response of the magnetometer to long and to short rectangular pulses of magnetizing current in a Helmholtz coil system. The time-constant of the response is about 100 μs. Fig. 4 shows the linearity of the response of the magnetometer in the range of fields measurable. The magnetic field strengths were calculated from the dimensions of the coils and the measured current. The gradient in Fig. 4 is 12·5 V/oersted and for any constant field the drift in the output voltage is about 1 mV/min, largely owing to variations of the mains-supply. The smallest field measurable is thus of the order 10^{-4} oersted. The magnetometer could be greatly improved in all respects by eliminating the phosphor of the cathode-ray tube, and the light-sensitive cathode of th photomultiplier by combining the two tubes in one vacuu system. The shutter would be replaced by an electrode the potential of the final anode. The high-frequency respon would then be limited only by the transit time of the electron and the size and complexity of the probe unit could reduced.

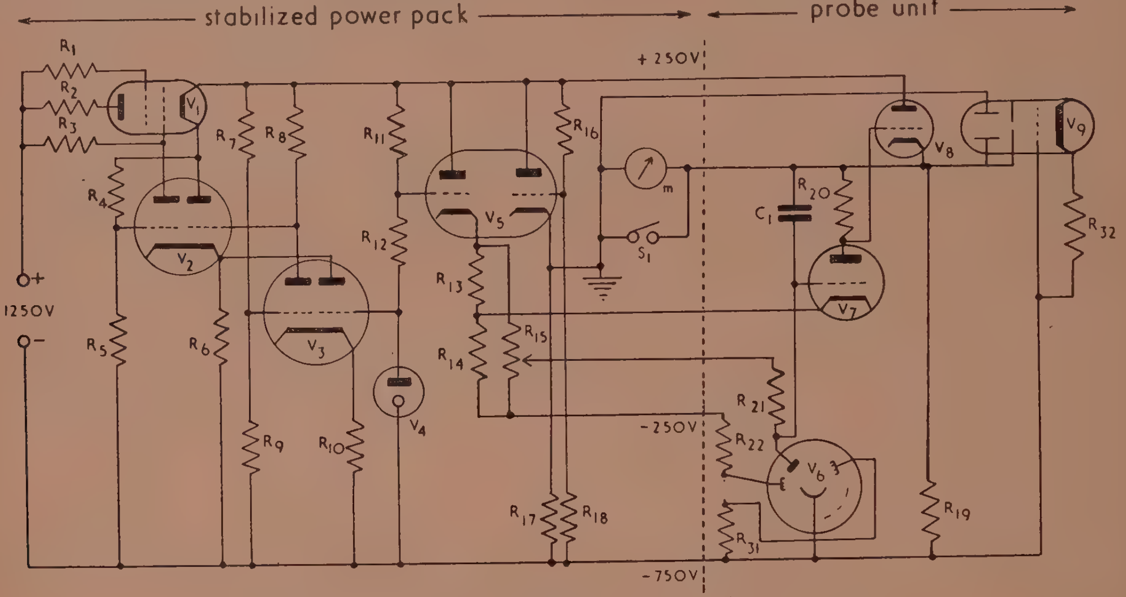


Fig. 2. The circuit diagram of the probe-unit and power-pack

R_1, R_2 = 47 Ω
R_3 = 100 kΩ
R_4, R_5 = 250 kΩ
R_6 = 100 kΩ, 3 W
R_7 = 750 kΩ, 2 W
R_8 = 250 kΩ
R_9 = 88 kΩ
R_{10} = 33 kΩ

R_{11} = 68 kΩ, 5 W
R_{12} = 50 kΩ, 3 W
R_{13}, R_{14} = 4·7 kΩ
R_{15} = 25 kΩ, helical
R_{16} = 100 kΩ
R_{17} = 150 kΩ, 4 W
R_{18} = 300 kΩ, 2 W
R_{19} = 150 kΩ, 7 W

R_{20} = 100 kΩ
R_{21} = 160 kΩ
R_{22} to R_{31} = 7·5 kΩ
R_{23} = 100 kΩ
V_1 = 12E1
V_2, V_3 = 6 SC7
V_4 = VR 105

V_5 = 6 SN7
V_6 = 27M1
V_7 = 6 BS7
V_8 = 6J6
V_9 = 1CP1
C_1 = 20 pF

All resistors are wire-wound or of high-stability carbon, the ratings are 1W unless otherwise stated.

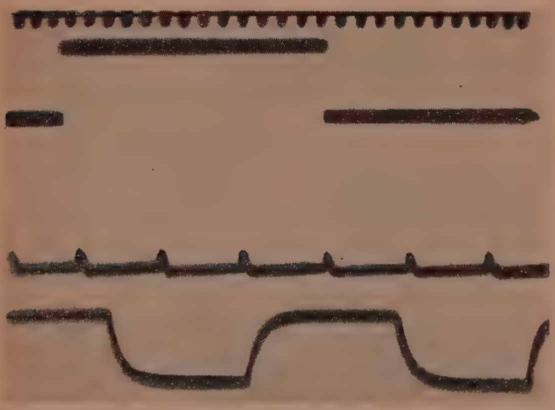


Fig. 3. The response of the magnetometer to a field of 0·15 oersted produced by a Helmholtz coil system in which the magnetizing current is switched on and off. Upper pair of traces: marker 1 c/s. Lower pair of traces: marker 1 kc/s

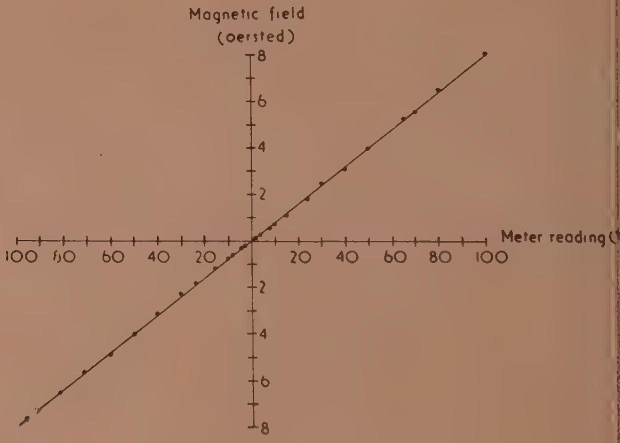


Fig. 4. The response of the magnetometer to steady magnetizing currents in the Helmholtz coil system. The radius and separation of the coils was 5 cm

ACKNOWLEDGEMENTS

I wish to thank Professor L. F. Bates for helpful criticis and Professor J. Z. Young for the use of the resources of department.

A photoelectric light-spot-displacement detector

By Å. Thulin, Bureau International des Poids et Mesures, Sèvres, S.-et-O., France

[*Paper first received* 17 *May, and in final form* 7 *July*, 1955]

The detector described employs a differential cadmium sulphide photoconductive cell connected in a bridge circuit. The use of a stabilized current for supplying the bridge permits a linear calibration that is independent of variations in spot intensity and photosensitivity. The output current is sufficient for operating pointer micro-ammeters or sensitive pen recorders without amplification. Theoretical and practical results are given.

hotoelectric light-spot-displacement detectors are used for iagnifying the deviations of the light beam in sensitive istruments having lamp and mirror indication, thus per-iitting reading or recording of the measured quantity by ieans of an electrical instrument. They are also used in arious servomechanical recording or regulating devices.

A great number of these detectors have been described in ie literature, especially for use as galvanometer amplifiers. he photoelectric receivers generally employed are thermo-ouples or barrier-layer cells connected to a relatively sensitive alvanometer, or photoemissive cells necessitating in most ases electronic amplification. Cadmium sulphide photo-onductive cells or germanium photo-diodes recently put on ie market permit the use of a robust reading instrument vithout amplification, but are usually subject to instability artly due to their temperature-sensitive characteristics. he inconvenience of most light-spot-displacement detec-ors is their sensitivity to variations in light intensity, nd this is perhaps why they rarely appear in industrial istruments except as zero indicators. To obtain a stable alibration of galvanometer amplifiers it is usual to employ iore or less heavy negative feedback with the primary alvanometer,⁽¹,²⁾ a technique which is restricted, however, o applications where the primary instrument is an electrical ne. This paper describes a simple and highly sensitive etector that in itself is insensitive to fluctuations in both light itensity and photosensitivity.

DESCRIPTION OF DETECTOR

The receiver is a differential photoconductive cell as shown chematically in Fig. 1. A limited number of these cells vere specially manufactured for the author's experiments by ie French firm RBV-Radio-Industrie, but they are now vailable commercially. The sensitive element is a thin layer f cadmium sulphide F evaporated on to an insulating ipport. The layer is activated with a small amount of opper, silver or other metal using a thermo-diffusion method. he object of the activation is to produce and stabilize the hotoconducting properties but it also provides a means for iodifying these within wide limits.⁽³⁾ The layers thus repared have a very high dark resistance, usually higher ian 10 000 MΩ, while the resistance at illuminations of the order of 1000 lux may fall to a few thousand ohms depending on the active area and the mode of activation. The spectral response extends from 0·5 to 0·8 μ. The sensitive area of the differential cell is limited by three deposited electrodes c_1, c_2 and c_3 to form a narrow band having a uniform height h of 0·7 mm. The distance d between the electrodes c_1 and c_2 is approximately 1 mm. The photoconductive layer in the space between these two contacts is covered with an opaque paint film O. In order to protect the layer against humidity the support is enclosed in a cylindrical Perspex housing H having a diameter of 20 mm and a height of 6 mm. The cell necessitates no special optical elements, the light spot L (usually in the form of a small rectangle) is projected directly on to the centre of the cell so as to cover the borders of the three electrodes. The width b of the spot determines the measuring range and is, for sensitivity and linearity reasons, preferably limited to a few millimetres.

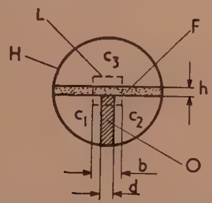


Fig. 1. Differential photoconductive cell

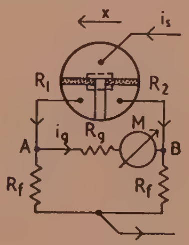


Fig. 2. Current generating detector

The cell is connected with two fixed resistances R_f to form a bridge circuit as is shown in Fig. 2. The main feature of the detector is the use of a constant current i_s for supplying the bridge circuit. For this a current stabilizer of simple construction is used.

CIRCUIT THEORY

The characteristics of the detector may be calculated by considering a differential cell having two separate and identical photoconductive layers, as in Fig. 2. Also assume that the parts of the photosensitive layers which are not illuminated are non-conducting and that the sensitivity of the layers as well as the illumination of the spot are uniform. If the light spot L moves in the x-direction, x being taken as the distance between the centre of the cell and that of the spot, the resistances between electrodes c_1 and c_3 and between c_2 and c_3 will be respectively

$$R_1 = f\left(\frac{1}{E}\right)\frac{h}{p+x}, \quad R_2 = f\left(\frac{1}{E}\right)\frac{h}{p-x}$$

and the resistance of one arm of the cell for $x = 0$

$$R_0 = f\left(\frac{1}{E}\right)\frac{h}{p}$$

Here $f(1/E)$ signifies the resistivity of the layers at the illumination E and p is the distance $(b - d)/2$.

Detector used as current generator. The current through the measuring instrument M (for instance a micro-ammeter) is found to be

$$i_g = \frac{i_s}{2}\cdot\frac{x}{p}\left[1 + \frac{R_g}{2R_f} + \frac{1}{a_i}\left(1 - \frac{x^2}{p^2}\right)\right]^{-1} \qquad (1)$$

where $a_i = 2R_0/R_g$. If the resistance of the instrument is much less than that of the cell (i.e. if $a_i \gg 1$), expression (1) is reduced to

$$i_g = \frac{i_s}{2}\cdot\frac{x}{p}\left(1 + \frac{R_g}{2R_f}\right)^{-1} \qquad (2)$$

Thus if i_s is kept constant, the current measured with the instrument M will be a linear function of the displacement x and independent of fluctuations in sensitivity of the cell or in illumination of the spot. To increase sensitivity the ratio $R_g/2R_f$ should be made small.

Detector used as voltage generator. If the detector is to be employed as a control element for an electronic amplifier its voltage sensitivity is of interest. The potential difference between terminals A and B when the instrument M is disconnected (R_g infinite), becomes

$$V_g = i_sR_f\cdot\frac{x}{p}\left[1 + \frac{1}{a_t}\left(1 - \frac{x^2}{p^2}\right)\right]^{-1} \qquad (3)$$

where $\qquad a_t = R_0/R_f$

If $a_t \gg 1$, the expression (3) is reduced to

$$V_g = i_sR_fx/p \qquad (4)$$

In order to increase the probability of obtaining an equal sensitivity in the two arms of the cell, there is actually no optical or mechanical separation in the photoconductive layer (see Fig. 1). This, however, does not much influence the expressions found, as the shunt resistance thus formed between the two arms is usually high.

SENSITIVITY CONSIDERATIONS

The sensitivity of the detector is limited by the maximum current i_s that can be employed without destruction of the photoconductive layer due to excessive heating. With the cells used the power dissipation should not exceed 1 mW/mm^2 active area. If the factors a_i or a_t are high the power dissipation per unit area will be independent of x and may be written as

$$W = \left(\frac{i_s}{2p}\right)^2 f\left(\frac{1}{E}\right) \qquad (5)$$

or

$$W = \left(\frac{V_0}{h}\right)^2 \Big/ f\left(\frac{1}{E}\right) \qquad (6)$$

where V_0 is the voltage measured between the common electrode of the cell and one of its differential electrodes.

From equation (5) it will be seen that with constant current the risk of destruction increases with diminishing illumination. When a current stabilizer is used it is therefore wise to put a security device in parallel with the bridge circuit so as to limit the maximum voltage on the cell to a value which, when multiplied by the stabilized current, gives the total maximum dissipation allowed. Such a device could be a polarized rectifier or simply a neon bulb, this latter having the advantage of giving visual indication. The prime function of the limiter is to guarantee protection of the photoconductive layer against prohibitive voltages which could arise from lamp failure or movement of the light spot off the cell.

The expressions (2) and (5) show that the highest curre sensitivity is obtained by using a high luminous intensity a a low-resistance cell. To maintain linearity the resistance the cell should, however, be high with respect to the instr ment resistance R_g.

The voltage sensitivity is a function of the resistance as well as of i_s. If the factor a_t is high the voltage on the c is found to be

$$V_0 = i_sR_0/2$$

and is thus independent of x. The expression (4) may th be written

$$V_g = (2V_0/a_t)(x/p)$$

A comparison of this formula with equation (6) shows th for a given power dissipation and a given a_t-value the volta sensitivity would be increased by using a low light intensi This, however, increases the response time of the phot conductor and it is here better to employ cells having high resistivity to obtain the same result.

CURRENT STABILIZERS

Under normal operating conditions, the voltage on t bridge will be between a few volts and 50 V. Thus, t current stabilization does not offer any difficulties. T types of stabilizers have been used. One employs a stal source of high voltage and a series resistance. A potent difference of 300 V is usually sufficient and may be obtain either from a dry battery or a neon tube stabilized sup (see Fig. 5). This very simple circuit has been found to g satisfactory results for most purposes, especially with lo resistance cells. Better stabilization was obtained by usi the plate current of a pentode tube for supplying the brid circuit. Both types of stabilizers were equipped with a ne bulb limiter connected between the output leads. The bulbs were of the small button type having no series resista and a striking voltage of about 65 V.

PRACTICAL RESULTS

The experimental characteristics of the cells ag extremely well with the theoretical predictions.

(i) *a_i- and a_t-factors.* As already pointed out, the worki conditions of the cells should be chosen so as to obtain hi a_i- or a_t-values. The influence of these factors has be determined experimentally with a cell connected as a volta generating detector, and is illustrated by the graph in Fig. A fixed light spot was used and the x-displacements w made by moving the cell with a micrometer screw. The fix resistances were each 10 kΩ and the different a_t-values w obtained by varying the voltage V_L of the lamp employ (nominal voltage 6 V). The graph shows that if a_t is hig than 20 the curves are linear and almost independent variations in light intensity. In fact a 100% increase illumination would then introduce a change in the $\Delta V_g/$ sensitivity of less than 3%. The results obtained can a be applied to a current generating detector. From formu (1) and (3) it will be seen that if R_g in the case of a curr generating detector is low with respect to R_f, the factor will have the same significance as a_t.

(ii) *Linearity.* Some small batches of cells have been tes for departure from linearity and the results are assembled the table. These show the departures as a percentage of total measuring range which was about ±1 mm. T measurements were made with the cells connected as curr enerating detectors and the readings were taken on a table alvanometer heavily shunted so as to obtain a very high -value. The intensity of the light spot was approximately 00 lux in all cases. The voltage V_0 measured across the cells ives an idea of their luminous sensitivity.

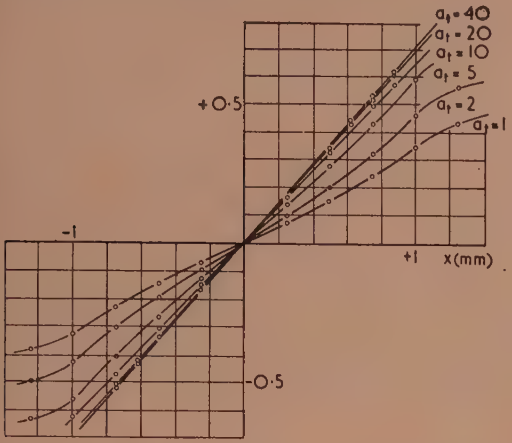


Fig. 3. Influence of a_f-factor on the calibration $V_g = f(x)$ for cell numbers 17–48; ($b = 3{\cdot}5$ mm; $i_s = 100\mu$A; $R_f = 10$ kΩ).

V_L (volts)	R_0 (kΩ)	a_f
8·5	10	1
6·7	20	2
4·6	50	5
3·6	100	10
3·0	200	20
2·6	400	40

(iii) *Influence of fluctuations in resistivity and illumination.* he voltage V_0 can vary considerably from one moment to another. Thus it can diminish by as much as 30% during the first few minutes after the cell current has been switched on. However, with a high a_i- or a_f-value and good current stabilization this seemed to have no influence on the sensitivity to spot displacements. The table also gives the relative values of the residual influence, on the differential sensitivity, of a 20% change in the voltage V_L of the lamp, i.e. of an increase or decrease of the illumination by a factor of about 2. This same variation can also introduce a slight shift in the zero of the bridge circuit, but usually the equivalent displacement of the spot is less than 0·01 mm.

Cell characteristics

ell number	Cell voltage V_0	Linearity %	Sensitivity $\frac{\Delta i_g}{\Delta x}$ µA/mm	Change in sensitivity in % for $\Delta V_L = \pm 20\%$
$i_s = 100\ \mu$A				
17–46	1·6	2	34·5	
17–48	1·4	0·5	35·5	∓3
30–11	1·5	1	29·0	2
30–32	1·4	3	28·0	0·5
30–42	1·5	0·5	25·5	1
$i_s = 50\ \mu$A				
35–22	1·0	1·5	14·3	1·5
35–33	4·3	1	15·3	1·5
35–55	1·2	2·5	14·0	1·5
35–59	2·5	1	14·5	1·5
35–60	1·5	1·5	15·0	1·5
35–63	3·2	1·5	14·0	2
35–66	3·7	3·5	14·5	1·5
35–70	1·8	1	14·5	1·5
40–63	23	0·5	15·4	2
40–64	22	2·5	16·1	2·5
40–65	22	4	16·8	4
40–70	21	2·5	15·4	2·5
40–71	15	4	15·1	3
40–73	20	1·5	15·5	1·5
40–77	42	1·5	15·4	3
40–78	23	1	16·7	1

(iv) *Noise and zero drift.* The semiconductor noise of the cells as expressed in terms of displacement of the spot, seems to be largely independent of the current i_s, but increases with the value of p. The manufacturer, by taking certain precautions in the choice of electrode material and activation technique, has been able to render it insignificant for most purposes. Thus for all the cells in the table and the measurement conditions stated above this noise corresponds to a displacement with an amplitude less than 0·001 mm as measured with a critically damped galvanometer having a free period of 3 s. No zero drift higher than the noise value was generally observed except for one series of cells where this drift attained in some cases 0·01 mm during the first few minutes after switching on. Thereafter the zero seemed to remain stable.

(v) *Time of response.* The response time of cadmium sulphide layers does not follow any simple exponential law.$^{(3)}$ In this particular application it was found convenient to define the time constant as the time required for the output current to attain 99% of its final value after a sudden displacement of the spot. The apparatus for its measurement comprised a direct current power amplifier and a Rapidgraph pen recorder (by SEFRAM, Paris) having a resonant frequency of 44 c/s and working at critical damping. The light beam was deviated by means of a small mirror attached to another critically damped oscillograph element. This was connected to a dry battery through a series resistance. A step displacement of the light spot was obtained by switching on or off the battery current with a telegraph key. Two cells out of each of three series listed in the table were tested using different illuminations. The results are given in Fig. 4. The time required for the pen to reach 95% of final indication was somewhat less than half the values given in the graph. The cells 17–46 and 17–48 show a much smaller time constant than the others. This is due to a slightly different manufacturing process.

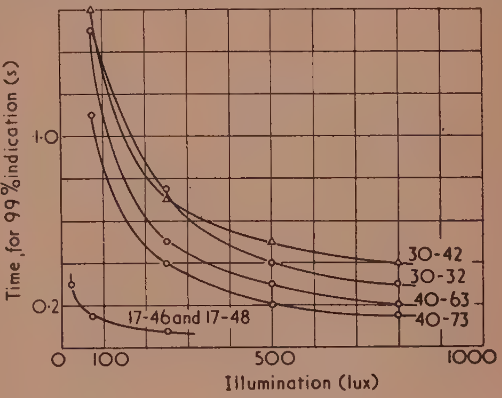


Fig. 4. Response time of cells as a function of illumination

As is seen from Fig. 4 it is important to use a high light intensity in order to obtain a short time response. Illuminations of the order of 500 lux are, however, readily obtained even with relatively small mirrors (6 to 10 mm in diameter) and with working distances between mirror and cell of up to 200 mm by using a small low-voltage lamp with concentrated filament (6 V, 0·8 A). A field lens giving an image of the filament in the object lens has been used throughout in order to obtain a uniform intensity of the spot.

USE OF DETECTOR FOR RECORDING

One of the most interesting properties of the detector is its adaptability for recording purposes. With low-resistance cells, spot widths of 3 to 5 mm and a light intensity higher than 500 lux a stabilized current of 100 up to 300 μA may be used. Although this is sufficient for operating ordinary pointer instruments as spot position indicators, it is insufficient for pen recorders of the galvanometric type. To permit an increase in the stabilized current it is necessary to increase the active area of the cell, to allow for a higher power dissipation. A special cell has been designed with increased height of the active surface. It is shown schematically in Fig. 5 and may be considered as composed of several simple cells connected in parallel by means of grid electrodes. One cell of this type has been tested using a light spot having a width of 7 mm and a height of 15 mm.

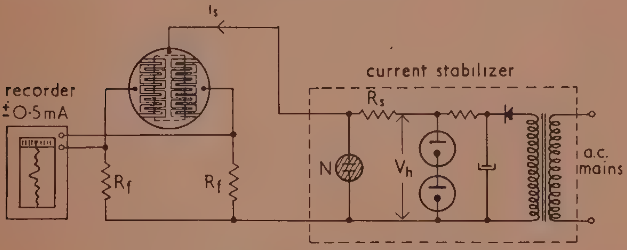


Fig. 5. Cell used for direct recording

$R_f = 47\ \text{k}\Omega$, 1 W
$R_s = 250\ \text{k}\Omega$, 4 W
$V_h = 300$ V (stabilized)
$N = 65$ V neon bulb (normally not conducting)

When choosing a suitable pen recorder the linearity factor a_l has also to be taken into account. Using expression (5) this can be written

$$a_l = 2R_0/R_g = 2Wph/(i_s/2)^2R_g = P_0/P_g$$

where P_0 is the total power dissipated in the cell and P_g the power dissipated in the recorder for a current equal to $i_s/2$.

The instrument employed by the author was an Esterlin Angus 1 mA recorder having an internal resistance 1400 Ω. A cell current of 1·2 mA was furnished by a simp resistance stabilizer. The normal working conditions of t cell were such that the total dissipation in it was abo 20 mW. The corresponding a_l-factor was thus of the ord of 40. The degree of linearity was found to be within a fe per cent of the measuring range and an increase or decrea in light intensity by a factor of 2 seemed to have no influen on the calibration.

An alternative method for obtaining a record is to use electronic amplifier as an intermediary. In this case a hig resistance cell of the type shown in Fig. 1 is chosen. T output voltage of the detector will be a compromise with t linearity. With an a_l-factor of 10, a maximum output ±4 V is easily attained which is sufficient for directly operati power tubes. A third possibility of using the detector f recording is to employ it as a sensing element in a serv mechanical recorder of the spot-follower type. One record of this kind has already been described as a commerci instrument.(4)

CONCLUSIONS

Due to its simplicity, reduced dimensions and reliabili the detector might be useful in laboratories and in indust as an inexpensive means for telemetering, regulation recording. A noteworthy application is its use as mechanical-electrical transducer. A simple pivoted mirr may produce a movement amplification of several hundr times, thus making possible the measurement or recording displacements down to 0·1 μ. Special amplifying mechanis permit still higher sensitivities.

ACKNOWLEDGEMENTS

The author is indebted to Dr. P. Goercke for advice co cerning choice of the type of cell, to RBV-Radio-Industr for the manufacture of the cells, and especially to Mess Tarbès, Trouvé and Stevenin of this firm for their valua co-operation.

REFERENCES

(1) Preston, J. S. *J. Sci. Instrum.*, **23**, p. 173 (1946).
(2) Copeland, K., Downing, A. C., and Hill, A. V. *J. S Instrum.*, **30**, p. 40 (1953).
(3) Goercke, P. *Ann. Télécom.*, **6**, p. 325 (1951).
(4) *Mesures et Contrôle Industriel*, **19**, p. 829 (1954).

An analogue computer for nuclear reactions

By E. S. SHIRE, M.A., Cavendish Laboratory, University of Cambridge

[*Paper received* 1 *April*, 1955]

Given the energy of the incident particle and the Q-value of the reaction, the energy of the emitted particle can be read directly from the computer for any angle in laboratory or centre of mass space. The ratio of the number of particles emitted per unit solid angle in centre of mass space to the corresponding number measured in laboratory space can also be read directly.

a nuclear reaction experiment it is often necessary to know e energies of the particles emitted at various angles, not ly for the reaction under investigation but often for re-tions due to impurities or backing material. The centre mass angles corresponding to laboratory angles and the tio of the number of particles emitted per unit solid angle centre of mass space to the corresponding number measured laboratory space are also often required. The analogue mputer described below provides a means of obtaining ese quantities quickly.

PRINCIPLE OF THE COMPUTER

If energy Q is released in a reaction,

$$Q = (M_1 + M_2) - (M_3 + M_4) = E_3 + E_4 - E_1 \qquad (1)$$

here the subscripts refer to particles as shown in Fig. 1 d the struck nucleus is assumed initially to be at rest. ee Mandeville* for this and other relations used.) The elocity V_4 of the particle emitted in laboratory space at gle θ to the incident beam is related to the velocity V_4^{CG} f the particle in the centre of mass co-ordinate system and the velocity V^{CGS} of the centre of mass in laboratory ace by the vector diagram shown in Fig. 2, where

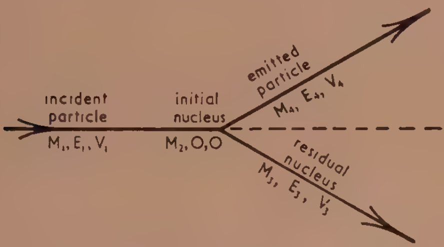


Fig. 1. The nuclear reaction

$$V_4 = \left[\left(\frac{2}{M_4}\right)E_4\right]^{\frac{1}{2}} \qquad (2)$$

$$V_4^{CG} = \left[\left(\frac{2}{M_4}\right)\left(Q + \frac{E_1M_2}{M}\right)\left(\frac{M_3}{M}\right)\right]^{\frac{1}{2}} \qquad (3)$$

$$V^{CGS} = \left[\left(\frac{2}{M_4}\right)\left(\frac{E_1M_1M_4}{M^2}\right)\right]^{\frac{1}{2}} \qquad (4)$$

d $$M = M_1 + M_2 = M_3 + M_4 \qquad (5)$$

hus V_4 can be obtained from V_4^{CG} and V^{CGS} for any angle f ejection θ in laboratory space, or β in centre of mass space, by a mechanical linkage in which, for a given reaction, V_4^{CG} and V^{CGS} have the constant values given by equations (3) and (4). If the common factor $(2/M_4)^{\frac{1}{2}}$ is removed from equations (2), (3) and (4) above and distances on the linkage are marked off on a square root scale in energy units (MeV), so that PQ (scale A) $= (E_1M_1M_4/M^2)^{\frac{1}{2}}$; QR (scale B) $= \left\{[Q + (E_1M_2/M)](M_3/M)\right\}^{\frac{1}{2}}$; PR (scale C) will be $(E_4)^{\frac{1}{2}}$ and so E_4 may be read directly.

The same linkage can be used to find the correction factor necessary to convert the number of particles $N(\theta)$ measured per unit solid angle at an angle θ in laboratory space to the number $N(\beta)$ emitted per unit solid angle at the corresponding angle β in centre of mass space.

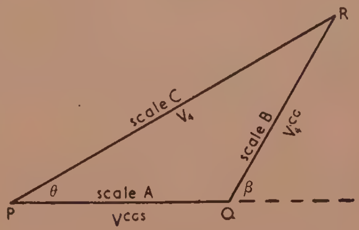


Fig. 2. Vector diagram relating velocities in the centre of mass and laboratory systems of co-ordinates

For $N(\theta) \sin\theta d\theta = N(\beta) \sin\beta d\beta$ where

$\sin\beta d\beta/\sin\theta d\theta$

$$= [2r\cos\theta + (1 - r^2\sin^2\theta)^{\frac{1}{2}} + r^2\cos^2\theta]/(1 - r^2\sin^2\theta)^{\frac{1}{2}}$$

$$= 1 + 2r\cos\theta + r^2(1 - \tfrac{3}{2}\sin^2\theta) + 0(r^4)$$

provided

$$r = \frac{V^{CGS}}{V_4^{CG}} = \left\{\left(\frac{E_1M_1M_4}{M^2}\right)\Big/\left[\frac{Q + (E_1M_2)}{M}\right]\left(\frac{M_3}{M}\right)\right\}^{\frac{1}{2}} \ll 1$$

In Fig. 2, $(QR)^2 = (PR)^2 + (PQ)^2 - 2PQ.PR.\cos\theta$ so that if $PQ/QR = 2r$, $PR/QR = 1 + 2r\cos\theta - 2r^2\sin^2\theta + 0(r^4)$. Thus PR/QR can represent $N(\theta)/N(\beta)$ to an accuracy of the order of $r^2(1 + \frac{1}{2}\sin^2\theta)/(1 + 2r\cos\theta)$, i.e. to 1·5% or better for $r \ll 0{\cdot}1$. In practice it will usually be more convenient to obtain $N(\beta)$ from $N(\theta)$ and this can be done by using a fixed (unit) length (B') on QR and dividing PR to give a reciprocal scale (scale C') from which $N(\beta)/N(\theta)$ can be read directly for a given value $2r$ of PQ (scale A').

CONSTRUCTION AND USE OF THE INSTRUMENT

Fig. 3 shows the construction of the instrument, which was made of brass with the exceptions shown in the figure. The positions of the scale marks for scales A, B and C were

---

* MANDEVILLE, C. E. *J. Franklin Inst.*, **244**, p. 385 (1947).

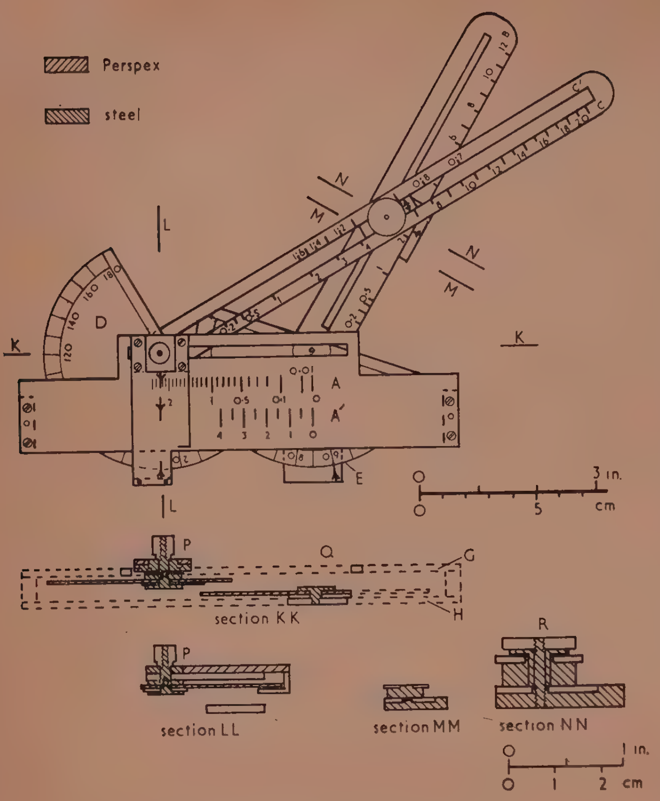


Fig. 3. Construction of instrument

obtained by multiplying figures from a table of square ro by a suitable factor. For instance, the 10 MeV mark $4{\cdot}4\sqrt{10} = 13{\cdot}91$ cm from the zero mark. For the lin scale A', 1 cm for $r = 0{\cdot}1$ was used. The correspond position for the mark B' was then 10 cm from pivot Q a the marks for scale C' were obtained by multiplying reciprocals of numbers from 0·7 to 1·6 by 10. Sc divisions were kept between 0·5 and 2 mm. (The fi divisions are not shown in Fig. 3.) Scales C and C' and th indexes were offset by 1 cm to avoid interference by the locking pivot R, and protractor E by 10° to facilitate read β when PQ is small. After adjusting the top and bott plates, G and H, to bring pivot Q under the centre line of slot in which P slides and opposite the zero of scale A, plates were fixed with tapered pins.

In use point P is set to the appropriate value on scale (A') and locked; joint R to the appropriate value on scale (the mark B') and locked to B. Joint R slides freely in and thus $E_4[N(\beta)/N(\theta)]$ can be read from scale C (C') angles θ and $\beta(\theta)$ as shown by protractors D and $E(D)$.

The instrumental accuracy is better than 1% in energy $\frac{1}{2}^{\circ}$ in angle provided the higher values of scales B and C used. This can always be arranged by multiplying scales A, B and C by the same suitable factor.

ACKNOWLEDGEMENT

I wish to thank Mr. F. W. Barnard for suggestions constructional details and for his care and skill in mak the instrument.

A fraction collector for chromatography

By E. T. Sanders, A.M.I.Mech.E., Unilever Ltd., Port Sunlight, Cheshire

[*Paper received* 6 *May*, 1955]

An instrument is described which collects, weighs and dispenses successive fractions of liquid from a chromatographic column into a series of test tubes. The fractions are separated on a weight basis and the entire operation is automatic.

Owing to the increased use of chromatographic methods of analysis and to the difficulties normally encountered in collecting a large number of fractions, the need arose for an instrument specially designed to ensure simplicity and accuracy in this procedure. For this purpose an automatic fraction collector has been designed and made. Since this was completed, various commercial instruments have become available but, to the author's knowledge, none of them is based on the principles of the instrument to be described.

GENERAL PRINCIPLES

The instrument comprises a balance which collects and delivers equal fractions; and two receivers which collect the fractions and deliver them into 100 sample tubes arranged in two concentric circles on a motor-driven turntable. The rotation of the latter is controlled by the movement of the balance, a tilting mercury switch and relay being operated at each weighing.

BALANCE CONSTRUCTION

The balance, as shown in Fig. 1, consists of two parallel cantilever arms A, counterbalanced by a screwed rod and adjustable weights B. A pivoted trough C is mounted between and at one end of the pair of arms A, the trough being divided laterally, by a metal partition, into two equal compartments. The pivots supporting the trough are on an axis below its base. A control arm D is directed perpendicularly upw from the trough shaft and bears against a fixed stop E compensating weight is fitted perpendicularly downward maintain the control arm in contact with either the left right side of the stop E. The axis of the chromatograp

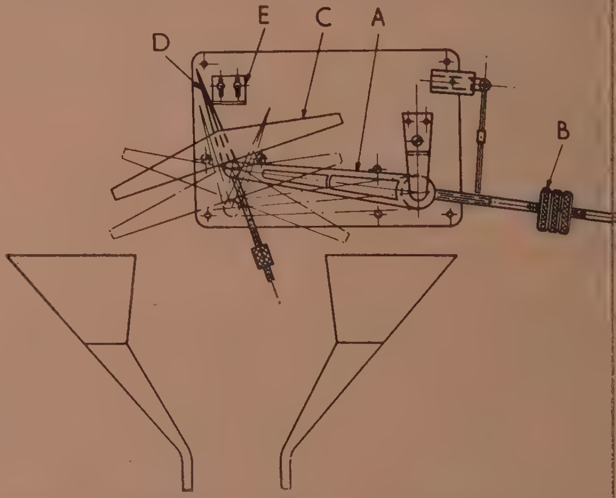


Fig. 1. Schematic diagram of balance with pivote trough and receivers

lumn is coincident with the trough shaft axis; but owing the fact that the trough shaft is displaced to a position low the trough, the centre partition moves well to the left right when the control arm is maintained against the stop. his ensures that the liquid will drip into the appropriate lf-trough without being "split" by the metal partition.

When empty, the trough is at its highest position owing to e inclination of the balance beam and is itself tilted to one de so that liquid is collected in the uptilted compartment. he fraction being collected causes a steady downward ovement of the balance beam until the required weight of quid is in the trough. At this position the apex of the ontrol arm escapes across the base of the fixed stop and—nce the centre of gravity of the liquid is to one side of the ntre line of the trough—a rapid swing of the trough occurs nd the fraction is transferred to the appropriate receiver. he balance beam now moves rapidly upwards to its original osition under the action of the counterbalance weights on e beam. The swing of the trough is sufficiently rapid to nsure efficient change of liquid collection from one com-artment to the other.

The process is repeated, the alternate halves of the trough eing filled and emptied into two separate receivers.

The stainless steel receivers terminate in small-bore tubes, ositioned to discharge into the sample tubes. The two eceivers are mounted on a hinged back-plate to facilitate emoval of the support plate with the filled tubes.

TURNTABLE CONSTRUCTION

The turntable, of Duralumin, has a mild-steel friction ring attached by screws. A type R.Q. geared motor (by The Drayton Regulator and Instrument Co. Ltd.) provides the drive through bevel gears to a rubber-sleeved cone which is in contact with the friction ring, the turntable rotating at approximately one revolution per thirteen minutes. The turntable is drilled to accommodate one hundred sample tubes and the periphery is machined with one hundred cam faces as shown in Fig. 2. Two aluminium support plates are drilled to agree with the main turntable. One plate is placed on the turntable and the sample tubes are fitted. After one revolution of the turntable, the support plate with the filled tubes can be lifted and removed to a bench stand provided. The spare support plate may be substituted on the turntable and sample tubes inserted for the next series of fractions.

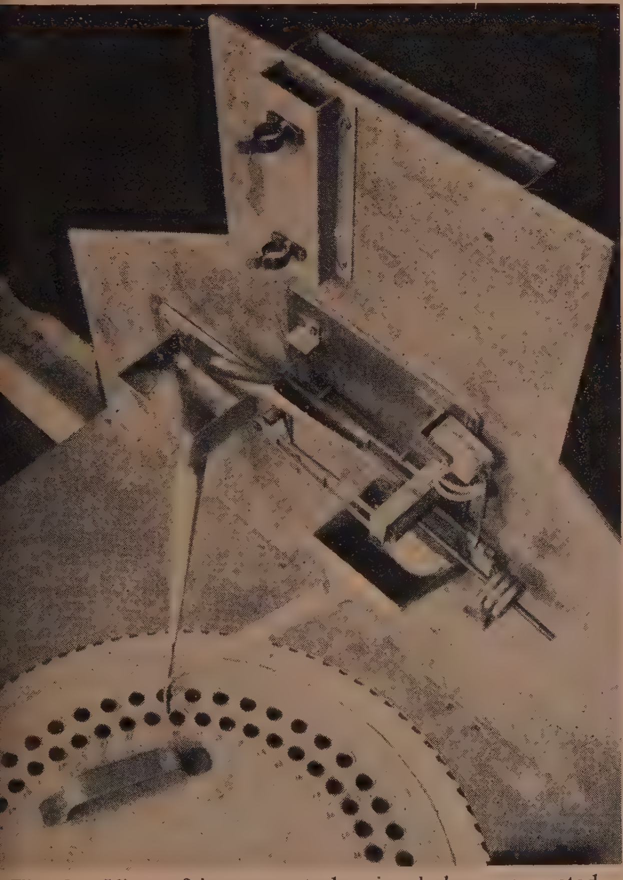


Fig. 2. View of instrument showing balance mounted, with receivers and turntable

CONTROL SYSTEM

A mercury switch, connected to the balance by an adjustable linkage, is mounted on the back plate of the balance. Since the filling time greatly exceeds the pouring time, the switch is so arranged that the motor is switched on during the shorter pouring period. A microswitch operating against the cam faces on the periphery of the turntable controls the angular movement of the table. As the mercury switch is "on" for too short a time to permit the necessary movement of the turntable to actuate the cam-follower on the microswitch with complete reliability, a special relay (made by Londex Ltd.) is added as shown in Fig. 3.

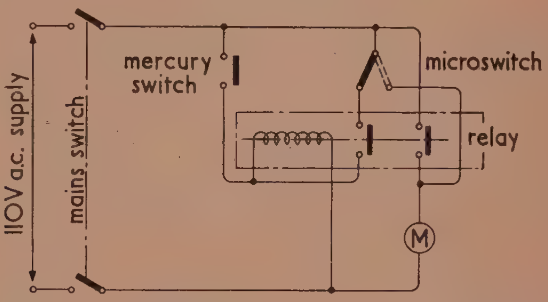


Fig. 3. Circuit diagram of control system. The mercury switch, micro-switch and relay contacts are in the position shown during filling of the trough

As will be clear from the diagram, the relay is actuated by the mercury switch and the contacts remain closed after the mercury switch is opened. The subsequent movement of the turntable closes the microswitch, which restores the relay to its original condition, the turntable movement continuing under the control of the microswitch until the cam-follower falls and the microswitch opens. The original conditions are thus restored until the next weighing re-starts the sequence.

EXPERIMENTAL FINDINGS

The instrument, as made, has an accuracy of approximately ±1% with respect to variations in volume of fractions collected. The small error is due to drop formation at the lips of the trough and at the ends of the small-bore tubes of the receivers. However, the performance of the instrument is considered satisfactory and no modifications have been carried out to overcome this small residual error.

ACKNOWLEDGEMENT

The author is indebted to the Directors of Unilever Ltd. for permission to publish this paper.

Tube wall thickness gauge with selection of backscattered γ-radiations

By J. L. Putman, M.A., F.Inst.P., S. Jefferson, B.Sc., J. F. Cameron, B.Sc., J. P. Kerry and E. W. Pulsford, B.Sc.,
Atomic Energy Research Establishment, Harwell, Berks.

[*Paper first received* 5 *May*, 1954, *and in final form* 7 *March*, 1955]

A gauge(1) is described in which γ-rays scattered back from a thickness of metal are distinguished from primary γ-rays by virtue of their reduced energy. The selection is achieved by using a scintillation counter with a sodium iodide phosphor as detector, followed by a single channel kicksorter as energy selector. The need for screening is thus eliminated and the source and detector can be mounted close together. This results in a light-weight measuring head, capable of very local measurement of thickness. The electronic circuit is arranged to permit single compensation for source decay so that constant calibration is preserved when using a ^{60}Co source.

The instrument is suitable for measuring the tube wall or plate thicknesses up to $\frac{7}{8}$ in. of steel and is particularly useful in detecting corrosion pitting in tubes.

It is already established that the thickness of a flat or curved metal sheet can be determined by measuring the proportion of γ-rays scattered back by the material. The principle has for some time been the basis of thickness gauges for use when only one side of a sheet of metal is accessible. It has special application to measurements of thickness of the walls of tubes when only the outside or only the inside of a tube is accessible.

In existing gauges a γ-ray source and a γ-ray detector are mounted in a precise geometrical arrangement on one side of the sheet along which the thickness is to be measured. In these gauges the detector, usually a Geiger counter, is screened from direct radiations from the source so that only the radiations scattered by the material to be measured contribute appreciably to the counting rate. Fig. 1(*a*) shows a typical arrangement in which the source is screened by a block of lead, or tungsten, from the detector.

Since the γ-rays must necessarily be fairly penetrating if thicknesses of the order of $\frac{1}{2}$–1 in. of steel are to be measured, it follows that the absorber which screens the detector must itself have dimensions of a few inches. One result of this is that the source and detector are well separated, and relatively large sources, of the order of 1 mc of radium or its equivalent in other γ-ray emitters, are necessary. The use of such a source in turn necessitates external screening to protect an operator using the gauge, and this screening together with the screening between source and detector tend to make the measuring head rather heavy.

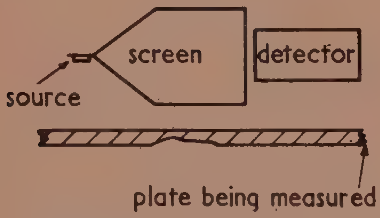
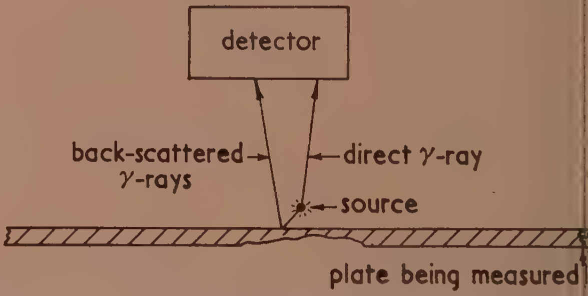


Fig. 1(*a*). Simple form of γ-ray backscattering gauge

An additional difficulty in the use of these instruments lies in the low angle between the radiations and the surface to be measured, resulting in poor localization of the area of measurement and a tendency to overlook local variations in thickness, such as pits resulting from corrosion in tubes.

PRINCIPLES OF SELECTION OF BACKSCATTERE RADIATION

In the instrument to be described,(1) the γ-ray sourc close to the sheet to be measured [see Fig. 1(*b*)], wh ensures good localization. Selection of the backscatte radiations by virtue of their energy change on Comp scattering enables the detector to reject direct radiations fr the source, avoids the necessity for screening and allows detector to be used close to the source, which may now h a much lower activity.



(*b*) γ-ray backscattering gauge employing energy selectio

It is well known that when a γ-ray is scattered throu 180°, its wavelength is increased by twice the Comp wavelength, that is, by 0·0485 Å. The corresponding cha in energy for high energy γ-rays is considerable. For ^{60} γ-rays with original energies of 1·33 and 1·17 MeV, the ba scattered radiations have energies of 0·214 and 0·209 M For the γ-rays from metastable ^{137}Ba following the integration of ^{137}Cs, the energy of which is 0·66 MeV, backscattered radiation has an energy of 0·184 MeV. I seen that for high energy γ-rays the energy of the ba scattered radiation does not vary much with the energy of initial γ-rays, but that there is a large energy differe between it and the direct radiation. In the instrument to described the detector is a scintillation counter, using phosphor a thallium-activated sodium iodide crystal. It been shown(2) that the amplitudes of pulses delivered fr such an arrangement are proportional to the energies absor from the radiations in the phosphor. A typical differen ias curve of a counter of this type when used with a 1 MeV -ray source is shown in Fig. 2, in which the dotted curve, eaking between points *A* and *B*, represents the changed hape of the bias curve when scattering material is placed ehind the source. The bias curve is seen to include a range f low amplitude pulses due to thermal noise in the photoultiplier. This is followed by a fairly uniform spectrum of ulses of various amplitudes almost up to that which correponds to the energy of the initial γ-rays. These pulses are ue to Compton recoil electrons produced by direct radiation pon the phosphor when the scattered γ-radiation escapes om the phosphor. Pulses of still higher amplitude correpond to the photoelectric absorption of direct γ-rays in the hosphor and these pulses correspond to the energy of photolectrons, that is to the energy of the original γ-rays, minus e K-level energy of the appropriate atoms of the phosphor.

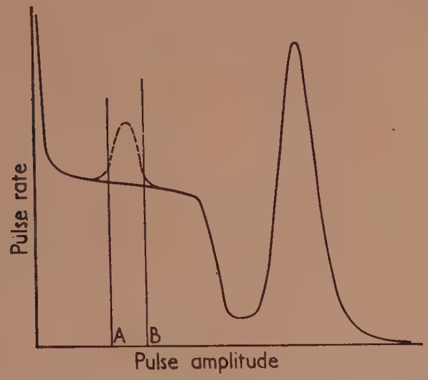


Fig. 2. Pulse amplitude distribution from scintillation counter; using sodium iodide phosphor with a source of 1 MeV γ-rays

The backscattered radiation gives rise to a similar pulse mplitude distribution corresponding to lower energies. The nportant feature is the presence of a photoelectric peak orresponding to the backscattered γ-ray energy of approxinately 0·2 MeV. This peak is superimposed on the Compton lectron distribution for the direct γ-rays and has a height in e diagram which is proportional to the number of backcattered radiations. It is by concentrating on this peak that electivity is obtained for backscattered radiations to the xclusion of the direct γ-rays.

DESIGN OF BACKSCATTERING GAUGE

The gauge, which is shown in Fig. 3, was developed for se in measuring tube wall thickness in an oil refinery. It omprises a light-weight portable measuring head which arries a small, low-activity ^{60}Co source, the sodium iodide rystal and the photomultiplier with its associated voltageividing resistor chain. This is connected through 200 ft f Telcon, AS91M, concentric cable (by The Telegraph onstruction and Maintenance Co. Ltd.) (characteristic npedance 110 Ω, capacity 11·5 pF/ft) to the analysing and isplay circuits which are housed in the same box as the oltage supply for the photomultiplier.

Fig. 4 shows the salient features of the measuring head, hich weighs 4½ lb. The source, in this case 3 mm of ½ mm iameter cobalt wire carrying an activity of 21 μc of ^{60}Co, mounted in a small slot in a thin brass rod and held in osition with a nickel sleeve. The sodium iodide crystal is enclosed in a thin brass housing, an extension to which supports the source at a distance of 1 in. from the face of the crystal. The eleven-stage photomultiplier (type 6260, by Electric and Musical Industries Ltd.) is shock-mounted in a turned brass case. (In fact only the first nine stages were used.) The resistance chain feeding the photomultiplier is mounted near its base. The whole of the rigid structure, comprising the brass case of the photomultiplier and the crystal source mounting, is suspended on shock mountings from an aluminium frame (see Fig. 3) which provides easy means of carrying the head. An additional spring-loaded

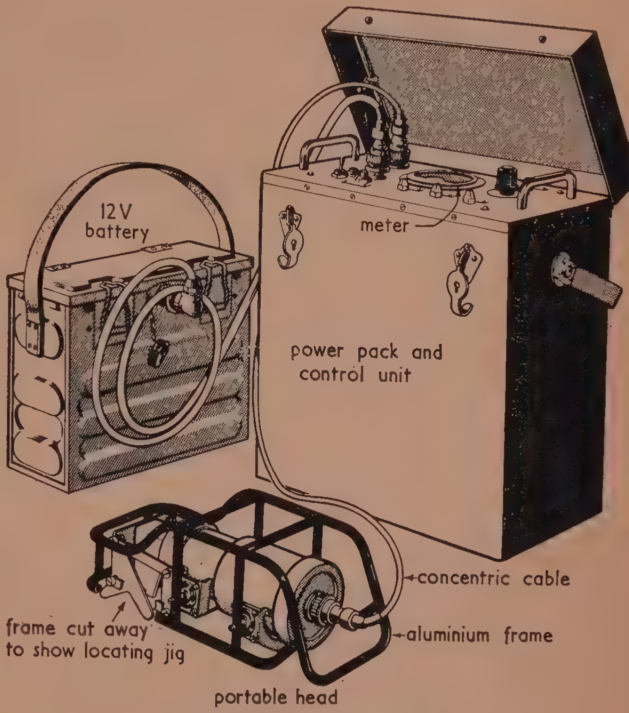

12 V battery
meter
power pack and control unit
concentric cable
aluminium frame
frame cut away to show locating jig
portable head

Fig. 3. Thickness gauge complete with battery

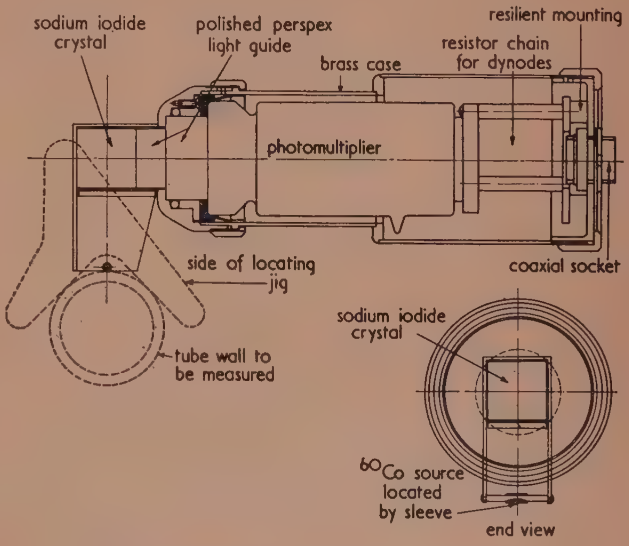

sodium iodide crystal
polished perspex light guide
brass case
resilient mounting
resistor chain for dynodes
photomultiplier
side of locating jig
coaxial socket
tube wall to be measured
sodium iodide crystal
^{60}Co source located by sleeve
end view

Fig. 4. Salient features of the measuring head

jig is attached to the photomultiplier head to enable the source to be located precisely in position with respect to a pipe or tube. When in position for measurement, the cobalt wire is parallel to the axis of the tube and is brought to within about 0·02 in. of the tube wall: the body of the photomultiplier is then at right angles to the tube axis. For measuring flat surfaces the jig can be pushed right back so that the source is brought up to 0·02 in. from the flat surface.

Pulses from the photomultiplier are fed by capacity coupling along the 200 ft of feeder cable to a pre-amplifier and a single channel kick-sorter which selects pulses of a narrow band of amplitudes around the backscattered photoelectric peak (2½–5 V) which correspond to points *A* and *B* in Fig. 2. These pulses are fed to a ratemeter circuit giving a meter indication of the backscattered count rate. Using the 21 μc ^{60}Co source, the total counting rate of pulses above 2½ V is 19 600 counts/s for a backscattering thickness of ⅞ in. of steel and 10 000 counts/s for zero thickness. The corresponding rates for selected pulses are about 9000 counts/s and 4000 counts/s respectively.

COMPTON RECOIL ELECTRONS

The contribution to the counting rate from the kicksorter which arises from the Compton recoil electrons in the phosphor (see Fig. 2) produces a background counting rate in the absence of any backscattering material. In practice, there is also a contribution from the nickel sleeve which holds the source in position. Both of these contributions are proportional to the activity of the source and would remain constant if the source did not decay. They are therefore backed off in the display circuits by applying a pre-set potential. An additional control enables the sensitivity of the count rate meter to be adjusted so that the pre-set backing-off potential exactly compensates the background counting rate to give a zero meter reading. It is evident that, by adjusting the sensitivity of the ratemeter in this way, automatic compensation is made for the decay of the radioactive source, so that the calibration of the whole instrument remains constant.

In an attempt to improve the photosensitivity of the crystal as compared with the Compton electron background, calcium tungstate crystals were used in an experimental arrangement instead of sodium iodide. The lack of energy resolution in these crystals, however, more than off-set the additional photoelectric sensitivity, and sodium iodide with its good resolution was found to be the better phosphor for this purpose.

DISTANCE OF SOURCE AND DETECTOR FROM SURFACE OF MEASUREMENT

In order to obtain the maximum possible backscattering from a given source and also the best ratio of the backscattered to direct radiation, it was found, as expected, that the source should be mounted as close as possible to the surface of measurement. The source was mounted on the surface for further experiments.

In the finished gauge, in which the source and detector are rigidly located at a fixed distance, the distance of the source from the scattering surface was not critical up to say 0·1 in., but did have an effect upon backscattered readings, which is expected to become more marked when measuring small areas or tubes of small diameter. Small external surface irregularities are therefore expected to have little effect on measurement of mean thickness.

The optimum distance for the detector is less well defin The fact that the backscattered radiations are discrimina within a narrow band of energies leads automatically to preference for backscattered rays which leave the surf nearly normally. This is equivalent to a certain degree collimation and the backscattered radiation at first falls less rapidly than the direct radiation as the detector is mov away from the source. Fig. 5 shows the relation betwe counting rate of the selected pulses and the distance of crystal face from the surface for a series of thicknesses material in an experimental arrangement. The resid

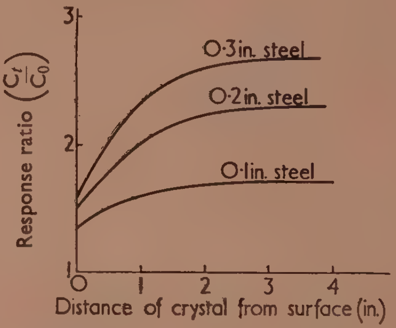


Fig. 5. Dependence of response on distance of detecto from source on scattering surface

C_t = total response; C_0 = response for zero thickness o metal.

counting rate in the absence of backscattering material is Compton electron background. It is seen that the dista of the detector is not critical and a distance of 1 in. chosen for practical convenience.

ELECTRONIC CIRCUITS

The block diagram, Fig. 6, shows the main features. the pulses from the scintillation counter are first ampli by a stage of linear amplification, the output of which applied to two similar amplitude discriminator circ operating at different bias levels, so arranged that the wan pulses trigger only the first discriminator, smaller pu

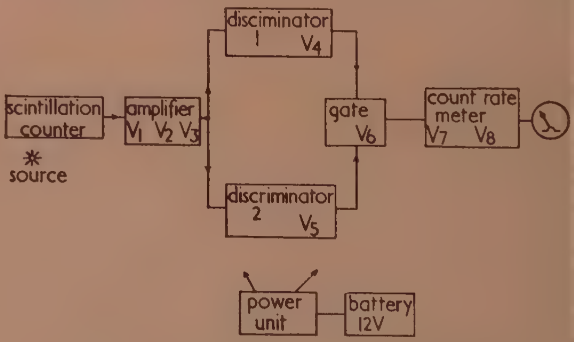


Fig. 6. Block diagram of thickness gauge

trigger neither, and larger pulses trigger both. The outp from these discriminators are applied to a gate circuit arran to give an output when one input only arrives. Follow the gate circuit is a count-rate meter circuit which comp e rate of occurrence of the pulses from the gate circuit, at is to say the count-rate of the γ-rays, the energies of hich fall in the wanted range. The result is shown on a eter, the readings of which give an indication of the thickess of the scattering material. In order to use the meter conomically, various backing-off circuits are provided to ppress the effect of unwanted pulses falling in the selection and. Two switched ranges of thickness measurement are rovided, one for the thinner materials (0–¼ in.) the other for e thicker ones (¼–⅞ in.).

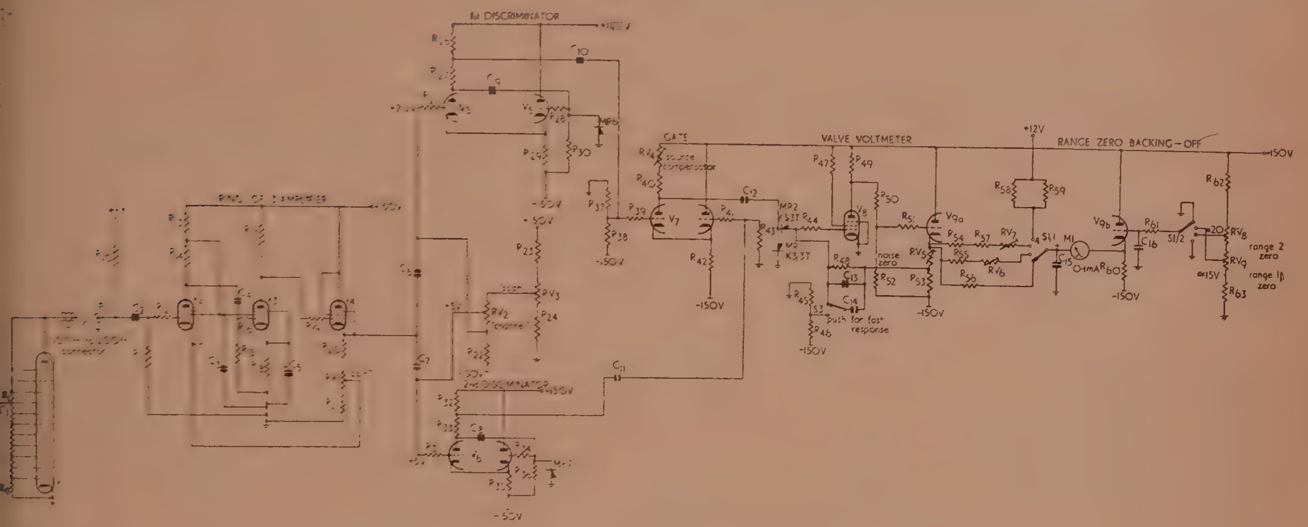


Fig. 7. Circuit diagram of thickness gauge

R_1–R_9 = 1 MΩ
R_{10} = 220 kΩ
R_{11} = 33 kΩ
R_{12} = 220 Ω
R_{13}, R_{14} = 10 kΩ
R_{15} = 470 kΩ
R_{16} = 220 Ω
R_{17} = 22 kΩ
R_{18} = 180 Ω
R_{19} = 220 Ω
R_{20} = 33 kΩ
R_{21} = 15 Ω
R_{22} = 1·5 MΩ
R_{23} = 470 kΩ
R_{24} = 22 kΩ
R_{25} = 220 Ω
R_{26}, R_{27} = 4·7 kΩ
R_{28} = 220 Ω
R_{29} = 33 kΩ
R_{30} = 1 MΩ
R_{31} = 220 Ω

R_{32}, R_{33} = 4·7 kΩ
R_{34} = 220 Ω
R_{35} = 33 kΩ
R_{36} = 1 MΩ
R_{37} = 47 kΩ
R_{38} = 820 kΩ
R_{39} = 220 Ω
R_{40} = 4·7 kΩ
R_{41} = 220 Ω
R_{42} = 33 kΩ
R_{43} = 1 MΩ
R_{44} = 220 Ω
R_{45} = 22 kΩ
R_{46} = 560 kΩ
R_{47} = 27 kΩ
R_{48} = 2 MΩ
R_{49} = 47 kΩ
R_{50} = 680 kΩ
R_{51} = 220 Ω
R_{52} = 1·5 MΩ
R_{53} = 47 kΩ

R_{54} = 330 Ω
R_{55} = 5·6 kΩ
R_{56} = 20 kΩ
R_{57} = 3·9 kΩ
R_{58} = 20 kΩ
R_{59} = 100 kΩ
R_{60} = 47 kΩ
R_{61} = 220 Ω
R_{62} = 120 kΩ
R_{63} = 12 kΩ

$RV1$ = 100 Ω
$RV2$ = 50 kΩ
$RV3$ = 25 kΩ
$RV4$ = 5 kΩ
$RV5$ = 2·5 kΩ
$RV6$ = 5 kΩ
$RV7$ = 2·5kΩ
$RV8$ = 5 kΩ
$RV9$ = 5 kΩ

C_1 = 50 pF
C_2 = 33 pF
C_3 = 8 μF
C_4 = 0·01 μF
C_5 = 25 μF
C_6, C_7 = 0·001 μF
C_8 = 100 pF
C_9 = 47 pF
C_{10}, C_{11} = 0·001 μF
C_{12} = 220 pF
C_{13} = 1·0 μF
C_{14} = 4·0 μF
C_{15} = 0·1 μF
C_{16} = 0·25 μF

V_1 = E.M.I. 6260
V_2–V_4 = 6AK5
V_5–V_7 = 12AT7
V_8 = 6AK5
V_{9a}, V_{9b} = 12AT7

The circuit diagram, Fig. 7, shows the linear amplifier $_2$, V_3, V_4) which amplifies all the pulses from the photoultiplier. The overall amplification of the photomultiplier d amplifier is adjusted so that the amplitudes of the wanted lses fall in the band between 2·5 and 5 V.

Following the amplifier is the single-channel pulse amplitude alyser, comprising the two (univibrator) trigger circuits $_5$, V_6) and the gate circuit (V_7) which selects for onward nsmission those pulses which lie in the wanted band. The tput from the gate circuit is passed to a count-rate meter cuit (MR_1, MR_2, V_8, V_9) of standard design(3) modified to t the requirements of the instrument. The metal rectifiers used instead of the usual double diode to economize in ater current.

Other modifications concern the economic use of the tput meter and its backing-off for the various ranges of the trument. In position 1 of the switch S_1 (as in the diagram) d with the scintillation head disconnected, the "noise o" control is adjusted to give zero indication on the meter. It is found that there are a few unwanted pulses (generated by the vibrator power unit and escaping through the filters) affecting the count rate circuit. These pulses are allowed for by setting the meter to zero in spite of their presence. On connecting the scintillation head, a reading is obtained because of pulses the amplitude of which falls in the selection channel. These pulses, arising from scattered radiations from the materials of the scintillation head itself, or from Compton scattering in the detecting crystal, cause a deflexion of the meter (0·8 full scale deflexion) and this indication is used to show that the overall performance is correct. If the standard deflexion is not obtained, then the source compensator is adjusted until the meter reads 0·8 full scale deflexion.

In position 2 of the range switch S_1, a backing-off voltage is applied to the meter *via* the cathode follower V_{9b}. This backing-off voltage is adjusted by R_6 to bring the meter to zero and effectively cancel the effect of all pulses arriving at the count-rate meter in the absence of a test specimen. Also, the sensitivity of the meter is increased by the reduction of the series resistance so that the reflected γ-rays from the thinner range of test specimens (0–¼ in. steel) produce deflexions within the meter range. Adjustment of the full scale deflexion to represent ¼ in. is done by adjustment of the series resistor while a ¼ in. standard test plate of mild steel is in position on the scintillation head.

In position 3 of the range switch S_1, further backing-off is applied in the same manner to reduce the meter reading to zero with the ⅞ in. plate in position, and the full scale deflexion is adjusted by experiment to represent $\frac{7}{8}$ in. On both ranges, intermediate calibration points are found by using the test plates of various thicknesses, and the results embodied in two calibration charts.

In position 4 the meter is used as a voltmeter (20 V full scale deflexion) to measure the accumulator voltage to ensure that it is adequate to run the instrument, the indications of which show errors when the voltage falls below 12 V.

In the count-rate meter circuit, the push button S_3 is used to alter the response time constant of the instrument from 10 to 2 s so that the initial part of the response occurs rapidly. The circuit arrangement ensures that when the button is released and C_{15} is re-connected, it holds approximately the correct charge, and a meter kick is prevented.(3)

The source of power is a 12 V, 22 A.h. portable accumulator, operating a vibrator-converter. Standard methods are used to generate the various voltages needed in the instrument.

PERFORMANCE

Calibration curves for flat plates, using the two thickness ranges, are shown in Fig. 8.

The readings of the meter are liable to error from several sources. Firstly, the instrument needs about 15 min after switching on from cold before all the circuits reach a steady state. Secondly, because of the random-in-time nature of the pulses in the system, the meter reading fluctuates about a mean position. The response time constant is arranged to be a compromise between magnitude of these fluctuations and rate of response. Usually the mean reading is estimated by eye after watching the meter needle for a short time. Thirdly, the battery voltage influences the readings, which rapidly gather large errors when the accumulator is nearly exhausted. This state of affairs is unmistakable in operation, being shown up by routine checks of the zero on either range and of the standard deflexion of 0·8 full scale deflexion on the first position of the range switch.

The stability of the circuits enables dependable thickness measurements to be made within ±4% over a thickness range of $\frac{1}{10}$ to $\frac{3}{4}$ in., using the integrating time constant of 10 s.

A special feature of this instrument is that the measurement of thickness is confined to a small area. A $\frac{1}{4}$ in. diameter pit $\frac{1}{8}$ in. deep on the inside of a $\frac{1}{4}$ in. thick tube is readily detected. An experimental arrangement showed that when the radius of a backscattering steel disk was increased, appreciable changes were obtained up to $1\frac{1}{2}$ in. radius. Most of the backscattered radiation, however, comes from the immedi
neighbourhood of the source. Partly for this reason there
very little difference in the calibration of the equipment
different diameters of tubes above about 4 in. diameter. T
response from a 4 in. diameter tube of thickness 0·2 in. w
found to differ by only about 5% from that from a flat pla

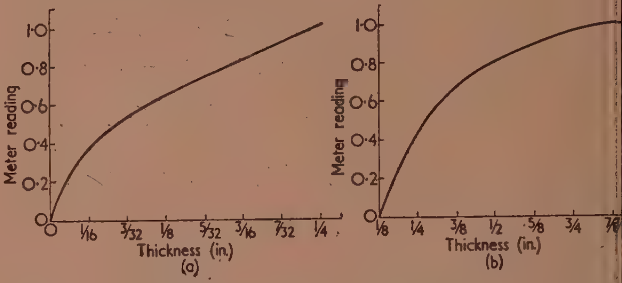


Fig. 8. Calibration curves for flat plates of mild stee
(*a*) Range 1, 0–$\frac{1}{4}$ in.; (*b*) range 2, $\frac{1}{8}$–$\frac{7}{8}$ in.

It is evident that the differences for larger diameter tu
would be smaller. Because of changes in geometry, separ
calibration curves are necessary for tubes of small diamet
especially for thick-walled tubes, but the differences betwe
these and flat plate measurements are smaller than in ba
scattering gauges of conventional types.

ACKNOWLEDGEMENTS

The authors wish to express their thanks to the Vacu
Oil Co. Ltd., for requesting and financing the developm
of this meter, and to Mr. R. B. Owen for help and loan
equipment during the early stages of development. T
mechanical design of the head was made by Messrs. T. Dy
and J. E. Boon in collaboration with the authors.

REFERENCES

(1) British Patent Application No. 17448/53.

(2) JORDAN, W. H., and BELL, P. R. *Nucleonics*, **5**, p.
(1949).

(3) COOKE-YARBOROUGH, E. H., and PULSFORD, E.
Proc. Instn Elect. Engrs, **98** (II), p. 161 (1951).

Laboratory and workshop notes

A method of machining slits and pinholes

By S. P. Middleton, National Physical Laboratory,
Teddington, Middlesex

[*Note received* 11 *November*, 1954]

he following method was primarily developed for the con-ruction of the pinhole source monochromator described sewhere.* The results obtained, however, proved successful nough to extend its use to a wider range of sizes and the escription has therefore been made a general one, rather han one related to the details of the monochromator alone.

Two important features of the method are (*a*) the apertures roduced by it are knife edged; (*b*) curved slits with accurately arallel edges can be produced as easily as straight slits.

The basic cutting technique remains the same throughout e range of sizes considered, but in view of the refinements ecessary for the smaller sizes, the range has been divided to three groups. In practice, there are no well-defined nits to each group and the sizes at which modifications in e method become necessary will vary with the type of uipment used and the quality of aperture required. So r, the only material used for the workpiece has been free-tting brass.

The cutting tool used, a Rigi Flat type engraving tool by aylor, Taylor and Hobson Ltd., is ground so that the cutting lges make an angle of approximately 35° to the axis. This ngle is not critical, but 35° has been found to be a reasonable mpromise between the acute angle desirable for size control nd the obtuse angle desirable for strength at the tool tip.

The tool is mounted in a rotating spindle, the bearings of hich must be free from appreciable shake if small apertures e to be cut accurately, and provision is made for the spindle be raised and lowered relative to the work by small and curately known amounts. If slits are to be cut, a lateral lative movement between work and tool is also required. he spindle speed used is not critical and, in general, the ghest speed obtainable without appreciable vibration should ove satisfactory. When apertures are required in material ore than 0·25 mm thick, a preliminary operation to reduce e local thickness is advisable. A tool of the form already scribed, but with the cutting edges making an angle of 50° the axis, is suitable for this "roughing" operation.

The equipment actually used for pinholes and slits down 0·065 mm was a light vertical milling machine with a 002 mm indicator mounted on the quill. In this machine, e fine feed control was sufficiently sensitive to permit the indle to be lowered by amounts as small as 0·0015 mm. urved slits were produced by mounting the work on a tary table. When smaller pinholes were cut, the milling achine was not available and an engraving machine, fitted th a spindle running in adjustable cone bearings and a tably mounted 0·002 mm indicator, was used with satis-tory results. To minimize burrs and local distortion of e surface containing the knife edge, it was supported over e region of the aperture by a backing plate. In the majority cases, a plate of mild steel has been used, but for the allest pinholes, Y alloy reduced the breakdown of the tool int and was quite effective in preventing burrs.

Large pinholes and slits in the range above 0·25 mm can be produced in brass to limits of ±0·01 mm by the normal cutting methods combined with measurements made optically between cuts. Before clamping the work on the backing plate, the tool is lowered until the point is just contacting the surface and the feed measuring device set to zero. Knowing the tool angle, the feed required to cut an aperture of a given size can be calculated and the first cut is taken with a feed less than that required for the full size aperture. The tool is then raised clear of the work and the aperture measured, this process being repeated until the correct size of aperture is obtained. To measure the aperture, a microscope with a vertical illuminator and either a linear scale graticule or micrometer eyepiece is arranged to view the work *via* a prism or reflector. In most cases, it will be found that the contrast between the brass work and steel backing plate is too small for the boundary to be visible. This difficulty can be overcome by "blacking" the brass with a chemical "bronzing" solution which gives it a deep bluish-black appearance, but leaves the steel unaltered. A solution which has proved useful for this purpose is made up with the following proportions: 100 g copper carbonate, 604 ml. 0·880 ammonia, 146 ml. water. The solution has to be left two or three days before it is suitable for use. For normal bronzing purposes, it can be used a number of times before it deteriorates, but for pinhole work, a fresh solution is advisable. To blacken the brass, a small quantity of the solution is dropped into the aperture and stirred with a dogwood peg or brush to remove any trapped air. After just sufficient time for blacking, which should be of the order of one minute, the aperture is washed clean with a jet of water. The cleaning water can be applied with a brush, but a jet is recommended as it helps to remove any sediment left at the bottom. The surplus water is then removed using blotting paper and the aperture cleaned and dried with an air blast. It will be found that slits can be measured accurately more easily than pinholes, but with care both can be measured with an accuracy of ±0·01 mm on sizes down to 0·2 mm, although the certainty of measurement is greatly dependent on the surface finish of the aperture walls: for sizes below 0·25 mm, the method of sizing described below is more reliable.

When apertures in the range 0·075–0·25 mm are cut the above method is modified as follows: (*a*) the size of aperture cut is arrived at by calculation and not by measurements made during cutting; (*b*) the tool must be ground in the machine spindle to ensure the tool point lies on the axis of rotation; and (*c*) a relatively high degree of surface finish is required on the tool, backing plate and work surfaces to prevent irregularities in the knife edge representing a large proportion of the full width or diameter.

To cut an aperture, the work and backing plate surfaces are first machined to be accurately in contact over the region of the aperture. In the case of apertures in a flat surface, this is a simple process; in other cases it may call for careful design and machining of the backing plate. After machining, the surfaces are polished to a degree depending on the maximum irregularity permissible in the aperture. For most purposes, the type of polish produced by very fine emery cloth should be adequate. The tool is then fitted in the machine spindle and ground; the method of doing this will mainly depend on the equipment available, but must basically consist of indexing the spindle in three positions at 120° to each other and traversing a grinding wheel across the tool, either by using the machine's own slides or by a separate attachment fitted on the work table. In selecting the type of wheel to use, the same criterion is adopted as in selecting the polishing material for the work and backing plate surfaces, though an additional factor is that the wheel must be capable of producing a tool point of width smaller than the size of aperture to be cut. After grinding, the tool point must be examined and its departure from the theoretical form estimated, as this will considerably affect the accuracy with which the depth of feed can be measured.

---

* Gates, J. W., and Middleton, S. P. *J. Sci. Instrum.*, **32**, 113–115 (1955).

To calculate the size of aperture from the tool angle and feed, it is necessary to know the precise feed reading at which the tool point makes contact with the backing plate. A simple and accurate method for determining this is by using an electrical continuity test. One side of a low voltage supply is connected by a brush to the revolving tool, the other side through a milliammeter to the backing plate. It is important that the spindle is running at its working speed when the test is made, as with some spindles the axial position of the spindle relative to its bearings may vary significantly with speed. If a low voltage resistance meter is available, it will provide all the circuit required and give a reliability of setting consistent with the aperture tolerance mentioned below. Although it would appear that the machine itself provides an alternative circuit, in the machines used so far this has not proved to be the case. Apparently the number of mechanical joints involved in the path form an open circuit to low voltage. Where the machine does provide a short circuit, it can easily be eliminated by insulating the backing plate from the machine table with very thin paper.

Using the above method, holes and slits of sizes between 0·075–0·25 mm can be cut with a size tolerance of ±0·0075 mm, although holding this tolerance is made easier if two or three trial apertures are cut first and measured independently, as this procedure tends to eliminate errors due to incorrect estimates of the true feed and shake in the spindle.

So far, no attempt to cut slits below 0·075 mm width has been made, but since above this size cutting slits has, if anything, been easier than cutting pinholes, it seems that slits down to 0·02 mm might prove quite practicable.

For pinholes, the method has been used down to 0·005 mm and has produced clean round holes, though below 0·05 mm there has been no certainty that the size would be as calculated or that every hole produced would be of good shape.

The only necessary modifications to the method are in the preparation of the tool, work and backing plate surfaces. After grinding, the tool must be lapped using a diamond wheel, and the work and backing plate surfaces must be lapped using a very fine loose abrasive.

Use of the method has shown that though it entails some experimental work in the initial stages while the characteristics and suitability of available equipment are being tested, it provides a quick practicable means of obtaining a wide variety of the apertures required in many optical instruments and test apparatus. From the results obtained so far, it appears possible that further development work would make the machining of pinholes and slits as small as 0·0025 mm a practicable proposition for any well equipped instrument workshop.

The author wishes to acknowledge the advice and co-operation received during the development of the method from Mr. W. G. H. Turl, Officer-in-Charge of the Light Division Instrument Workshop, from Mr. P. W. Kendall, of the Workshop staff, and from Mr. E. J. Tappere, formerly of the Workshop staff.

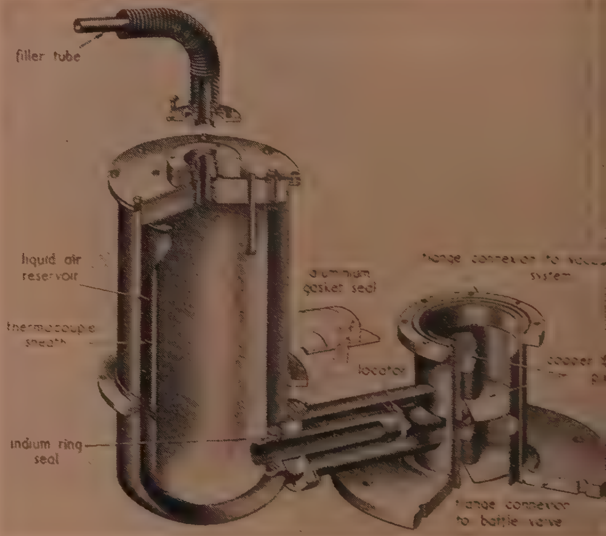
The work described above has been carried out as part of the research programme of the National Physical Laborat
and this paper is published by permission of the Directo
the Laboratory.

An improved high-conductance cold-trap

By A. J. MARTIN, B.Sc., Ph.D., United Kingdom Atom
Energy Authority, Aldermaston, Berks.

[*Note first received* 26 *November*, 1954, *and in final for*
20 *January*, 1955]

The conventional design of vacuum cold-trap for use wi
diffusion pump employs a cylindrical container, filled
the coolant, with a surrounding annular space connec
diffusion pump and vacuum chamber. The advantage
such a design lie in the large container volume, the l
surface area exposed to the chamber atmosphere and in
degree of insulation between the body of liquid coolant
the room atmosphere. These advantages, however, are o
to some extent by the relatively low gas conductance inhe
in such a design (conductance being the reciprocal of
resistance to gas flow) and by the inaccessibility of the li
container. Accessibility would be an advantage since deg
ing of the cold-trap walls is necessary occasionally, as
efficiency of a cold-trap decreases with time of use: degass
by heating would restore the original efficiency. Such hea
is difficult in the standard design, and removal of the con
surfaces from the vacuum system for the heating operatio
virtually impossible without dismantling the apparatus.



High conductance baffle trap with reservoir

A cold-trap design avoiding these disadvantages
recently been described by Pollard,* who tested the de
on a 3½ in. diameter vacuum line. The trap consisted o
open copper cylinder placed concentrically within the vacu
tubulation and divided along its length by three semi-circ
copper plates, so arranged that no direct path through
cylinder was presented to gas molecules. The cylinder
baffle plates were then cooled by contact with a solid co
bar, which was led through the wall of the chamber,

---

* POLLARD, J. E. *Rev. Sci. Instrum.*, **24**, p. 996 (1953).

ersed, outside the vacuum system, in a Dewar flask filled liquid air. A slight gap was afforded between the walls he chamber and the inner cylinder, the outer surface of ch was polished to minimize heat exchange by radiation. he advantages of such a design were stated to be threefold, hat only slight loss of efficiency resulted as the liquid level he Dewar fell; this liquid level could be followed easily, the baffle plates were accessible from the vacuum chamber easily demountable. Highly efficient cooling was claimed no serious loss of gas conductance.

bjections to the Pollard design, however, became apparent n a larger model was made for use with a 6 in. diameter uum line. Various diameters of copper bar were used and ying thicknesses of copper sheet for the inner cylinder and le plates, but, using a liquid air coolant, in no case could emperature lower than −40° C be attained at the top le plate. Even with extra insulation of the conductor , and with vacuum conditions maintained inside the cold- , the lowest temperature attained at the bottom baffle e was −100° C. The time taken for the system to reach owest temperature was about an hour, and a considerable in temperature inside the trap became apparent as the id air level in the outer Dewar vessel dropped.

o overcome these difficulties it was found necessary to rease the distance between the liquid air surface and the le plates. Replacing the conductor bar by a tube filled liquid air was found to give the best results, and enabled eservoir of liquid air to be used *above* this tube, thereby uring that the cold-trap temperature was not affected by liquid air level in the reservoir until this level fell below t of the tube. In this new design, shown in the figure, reservoir was a thin-walled stainless steel vessel, contained de a similar vessel, and insulated from it by glass wool he sides and a Sindanyo plate at the top. The boiling air allowed to escape to the atmosphere through an annulus rounding the filler tube. The filler tube was thereby led, thus minimizing liquid air losses by evaporation lst filling.

hermal losses to the atmosphere were also minimized by npletely insulating the whole length of the connector tube ning reservoir and cold-trap. This was achieved by joining cold-trap and the outer shell of the reservoir by two nged tubes, concentric with, and surrounding the con- tor tube. A thin stainless steel disk, brazed to the central e, was sandwiched between the two flanges, and a vacuum l was effected here with a 25-gauge aluminium gasket, ails of which are shown inset. To facilitate assembly and subsequent demounting, the connector tube was joined the reservoir by a screwed union, using a compressible ium O-ring seal. The use of the two metal seals referred was necessary since rubber seals were found to break vn at the service temperatures involved; other gasket terials could have been used, particularly at the indium l, since it was not a vacuum connexion.

The only thermal conduction paths to the room atmosphere re *via* the filler tube, the thermocouple sheaths inserted in trap (with which the liquid level could be followed), and thin vacuum sealing disk brazed to the connector tube.

A further improvement was made by leading the connector e to the centre of four baffle plates, thereby increasing the ling efficiency. The upper and lower pairs of baffle plates ld be removed from the top, for cleaning and degassing. When tested under vacuum conditions, the top baffle plate ained a temperature of −150° C, fifteen minutes after ng the reservoir with liquid air. Moreover, using a ervoir 4 in. diameter, 6 in. deep, the temperature of the cold-trap was maintained constant for four hours before refilling became necessary: a larger reservoir may well enable the trap to be in use unattended overnight. These characteristics showed substantial improvement compared with those of the original baffle plate design using a solid copper conductor bar. The conductance of the trap was determined as 150 l./s for air at 20° C.

An automatic cathode-ray oscilloscope beam brightening device for transient recordings

By J. Wood, Armament Research Establishment, Ministry of Supply

[*Note received* 29 *November*, 1954]

The photographing of transient phenomena displayed on cathode-ray oscilloscopes requires some form of beam brightening or beam control so that the beam is on only for the duration of the transient or some other time which can be pre-determined. This usually requires the use of additional circuitry and equipment.

A double-beam oscilloscope, (model 1035 by A. C. Cossor Ltd.), has been modified for automatic beam brightening to permit photographic recordings of transients. No other equipment is necessary other than the camera fitted to the oscilloscope. The beam is normally suppressed by turning down the brightness control. By utilizing a voltage derived from the time-base circuit and applying it to the grid of the cathode-ray tube, the application of a transient to the oscilloscope Y amplifier, which will trigger the time-base sweep, will automatically brighten the beam to maximum brilliance for the duration of the triggered sweep to which the oscilloscope time-base has been preset. The duration of the time-base triggered sweep (and the beam brightening) is variable and in nine ranges from 15 to 150 μs.

The speed of the beam brightening, i.e. the time taken to reach maximum brilliance after the triggering of the time-base by the transient, is not more than 3 μs and this time can be reduced to about 1 μs by suitable pre-setting of the ordinary brightness control on the front panel. The beam is normally kept off by turning down the brightness control fully anti-clockwise and with this setting the beam takes up to 3 μs to attain maximum brilliance after the commencement of the triggered sweep.

If, however, the brightness control is advanced clockwise from this position until the beam is only just visible, the time it takes to attain maximum brilliance is only 1 μs. This method possesses the additional advantage that the stationary spot is useful in marking the actual point of commencement of the sweep or transient on the film. (See photographs of transients, Fig. 1.) The top trace shows a pulse of approximately 11 μs duration displayed on a total sweep of 50 μs. The pulse has been delayed on the sweep so as to show the whole of the pulse characteristics. In the bottom trace the pulse has been used to trigger the 50 μs sweep and to brighten the beam so that the actual speeds of the time-base triggering and the beam brightening can be assessed. The time-base sweep has triggered at a point about 85% up the leading edge of the pulse corresponding to a delay in triggering of about 3 μs. The beam has attained maximum brightness within 1 μs of the commencement of the time-base sweep.

The writing speed, using the Cossor model 1428 oscilloscope, is about 3–4 mm/μs; this could be improved by substituting a blue-faced tube in the oscilloscope and by replacing the Cossor camera lens with one of larger aperture than $f/3 \cdot 5$.

When the time-base circuit is switched to "triggered" on the front panel the time-base circuit V_8 (Fig. 2), is converted to a transitron circuit, its screen being connected through a switch S_{12} to its suppressor electrode. Whenever the time-base is triggered, a steep-fronted pulse of some 70 V amplitude is made available at the screen of V_8.

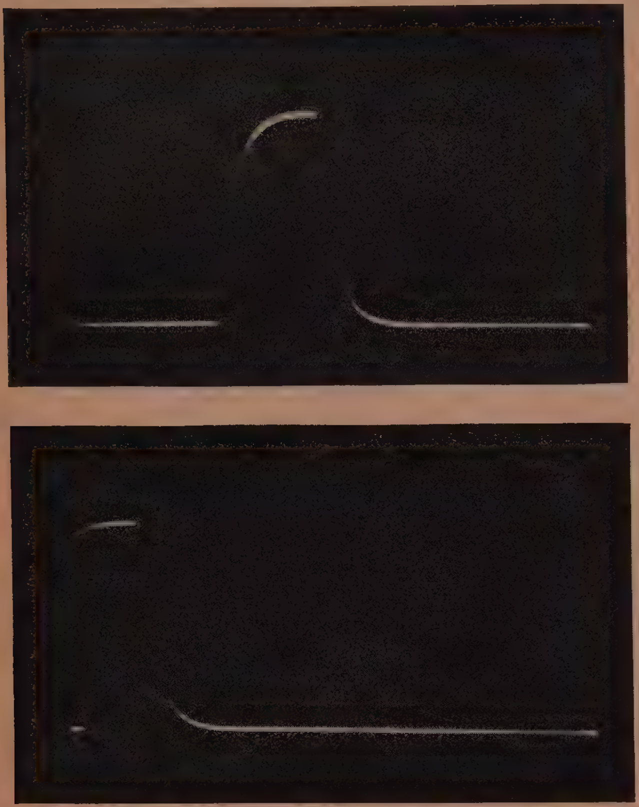


Fig. 1. Transient pulses displayed and photographed on oscilloscope with automatic beam brightening in operation

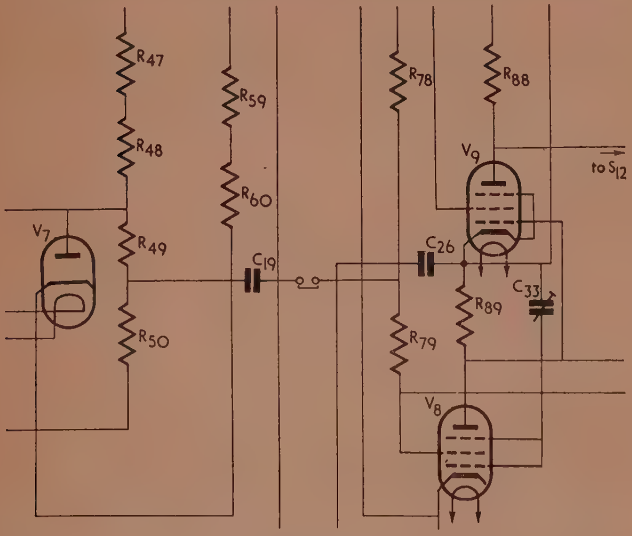


Fig. 2. Part of time-base and associated circuit before modification

If the level clamping diode V_7 is removed and the resistor R_{47} is disconnected, the grid of the cathode-ray tube will be driven positive by this pulse, which is approximately rectangular shaped, having a wavefront of a few microseconds and lasting for the duration of the triggered sweep. T positive pulse is not present under running time-base c ditions and the automatic beam brightening is only effect on triggered time-base.

The removal of the diode V_7 does not affect the operat of the flyback suppression and the modifications do prevent the oscilloscope from being used for other appli tions, nor do they seriously alter its performance. T modifications are simple and can be carried out in a f minutes:

(*a*) remove valve V_7 from its base; (*b*) disconnect *R* from earth (chassis); (*c*) turn down brightness control u the beam is sufficiently suppressed.

The method permits the photography of transient fron few millivolts peak and of a few microseconds duration, a the triggered sweep brightened for the whole of its durat provides a convenient approximate time scale. It is possi that this method is capable of being extended to ot oscilloscopes.

This note is published by permission of the Chief Scient Ministry of Supply.

Modifications to an air-driven ultra-centrifuge

By I. J. O'Donnell, M.Sc., Biochemistry Unit, Woo
Textile Research Laboratory, Melbourne, Australia

[*Note received* 7 *February*, 1955]

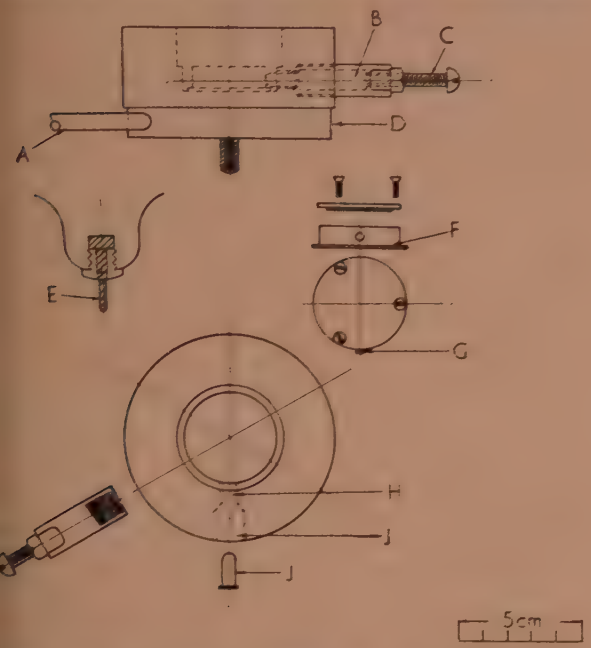
During experiments with a model 1948 ultra-centrifuge Phywe and Co., Göttingen, Germany) in these laborator an excessive temperature rise was observed in the ro While running at 45 000 rev/min in pure hydrogen a pressure of 3 mm of mercury, the rotor temperature increa by as much as 3 – 4° C per hour. The temperature of the ro was measured in air (not in the low-pressure hydrog before and after each run by inserting a thermistor int recess drilled in the balance cell of the rotor.

The Phywe rotor as supplied by the manufacturers stabilized by a pin projecting into a small ball-race situa in the bottom of the rotor, the rotor not being of the s balancing type used in the model E analytical ultra-centrif by the Specialized Instruments Corporation, California.

The heat rise was considered to be due firstly to the f tional heat generated by the rotor passing at high sp through the hydrogen, despite the low frictional coeffic and high thermal conductivity of this gas, and secondly heat generated in the small ball-bearing mounted inside rotor. These effects have been overcome by evacuating chamber (as in the Spinco instrument) to a pressure $2 - 3 \times 10^{-4}$ mm of mercury and by moving the stabili ball-race from the rotor to a water-cooled housing un neath. A stainless-steel pin was inserted in the bottom the rotor to pass snugly through the small ball-race. T pin has to be replaced from time to time when it beco worn through spinning in the ball-race. After making t modifications the temperature rise in the rotor when runn at 50 000 rev/min was only 0·5 – 0·6° C per hour.

The design of the water-cooled bearing support is show the figure. The smaller ball-race (type S.K.F. EL3 by Skefko Ball Bearing Co. Ltd.) is mounted inside a la ball-race (type S.K.F. 6000) and held there by two s circular metal rings pressed tightly into the larger r These two races are then mounted in a brass case with and bottom recessed in such a way that the outer edge of larger bearing is fixed while the inner ring of this bearin free to rotate.

he case is mounted flexibly in the water-cooled brass sing by six shock-absorbing pins, the lower surface of the e being lubricated by a small amount of silicone grease. ation of the case is prevented by a small protruding pin.



Water-cooled bottom bearing for the Phywe ultracentrifuge

1, water inlet; *B*, round section rubber; *C*, adjusting screw;), water jacket; *E*, stainless steel pin in bottom of rotor; , bottom of bearing holder recessed to clear inner race; , protruding pin; *H*, steel bushing to resist wear; *J*, six qually-spaced steel pins.

t is a pleasure to acknowledge the resourcefulness and hnical skill of Messrs. E. W. Walton, R. J. Hankin and C. Garnham in the construction of the bearing, diffusion mp and vacuum gauge.

A resistance thermometer with a high speed of response

By W. T. Bane, B.Sc., and E. R. Dymott, National Physical Laboratory, Teddington, Middlesex

[*Note received* 18 *November*, 1954]

is note describes an electrically-insulated resistance thermoter with a fast response,(1) which was designed for certain erimental work at the National Physical Laboratory, and ich, it is thought, may have other applications. Since the eral requirements to be met were a relatively large surface a, short thermal path and small heat capacity, it appeared t a thermometer wound in the form of an electrical resisce strain gauge might be suitable. Accordingly, a thermoter was constructed in this form, using the technique eloped here previously.(2)

About 17 in. (43 cm) of nickel wire of diameter 0·001 in. 0025 cm) was wound on a thin flat former of impregnated per, the ends of the winding being spot-welded to thin tal strips to provide connexions. The winding was then ally covered by a single layer of the same paper, and the it bonded together in a hot press. The resistance of the rmometer was 100 Ω approximately, and the dimensions of the winding about 1 by 0·2 in. (2·5 × 0·5 cm); the overall thickness was 0·005 in. (0·013 cm).

The response was measured by connecting it in one arm of a d.c. bridge network, the current through the thermometer being about 5 mA. The output signal from the bridge was passed, after amplification, into a high-speed recorder (by Kelvin and Hughes Ltd.). The amplifier used(3) had a sensibly flat response over the frequency range 0 to 100 c/s. A step change of temperature was produced by plunging the thermometer rapidly into hot water. The recorded response showed that the thermometer had a time constant of about 0·07 s. The response in stirred air was measured in a similar manner, and the time constant found to be about 1·5 s.

The authors desire to acknowledge the assistance received from Mr. W. J. Pullen and Mr. J. S. Appleby. This work was carried out as part of the research programme of the National Physical Laboratory, and this note is published by permission of the Director.

REFERENCES

(1) British Patent Application No. 8091/51.

(2) British Patent No. 560260.

(3) Tanner, J. A., and Harrington, B. G. V. *J. Sci. Instrum.*, **28**, p. 33 (1951).

A simple achromatic doublet for spectroscopic purposes

By N. J. Rumsey, M.Sc., A.Inst.P., Dominion Physical Laboratory, Lower Hutt, New Zealand

[*Note first received* 30 *March, and in final form* 3 *June*, 1955]

Achromatic doublets made of normal optical glasses for use in spectroscopes and similar instruments covering the visible spectrum should usually have their secondary spectrum adjusted so that the extreme visible violet and the extreme visible red are brought to foci at the same distance from the lens. For such lens systems we have found a design which is relatively simple but which results in good performance. It is derived from an ordinary cemented doublet telescope objective (in which the crown component is equi-biconvex and the flint plano-concave) by making the originally plane back surface of the flint slightly convex. A specification for such a doublet of 20 in. focal length and 2 in. clear aperture is as follows:

Radius (in.)	*Thickness (in.)*	*Glass*
$r_1 = +8{\cdot}79$	$t'_1 = 0{\cdot}4$	HC 519604
$r_2 = -8{\cdot}79$	$t'_2 = 0{\cdot}3$	DF 620362
$r_3 = -266$		

The lens thicknesses are not critical. The glasses are regarded by Chance Bros. Ltd. as standard for telescope objectives, so should be particularly readily available. Zonal spherical aberration, chromatic variation of spherical aberration and coma are all slightly smaller than in the objective from which this design was derived. The wavelength of best spherical correction (as well as the wavelength of minimum focal length) is shifted towards the blue, so that the residual spherical aberration (over-corrected) in the extreme violet turns out to be about the same fraction of the Rayleigh limit as the (undercorrected) aberration in the extreme red. Coma is not corrected, but is not objectionable over the small field usually required in this application.

Correspondence

Logarithmic device for a densitometer*

In the design of a direct-reading photoelectric densitometer some form of logarithmic device is necessary in order to provide a linear density scale on the reading dial. Various electrical methods have been proposed but the majority are not completely successful since the logarithmic relationship is only obeyed approximately.

One method which gives a voltage output accurately proportional to the logarithm of the input current uses the relation between the anode current and anode voltage of a thermionic diode operating in the retarding field region. The performance of such an arrangement has been described in earlier papers$^{(1,2)}$ but the system described in this note has an improved means of ensuring stability.

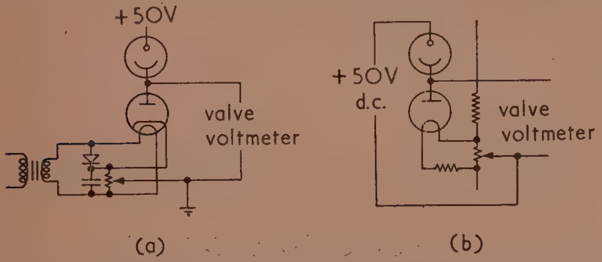


Fig. 1. Circuits with compensation for heater voltage: (*a*) indirectly heated diode, (*b*) directly heated diode

A major disadvantage of the method lies in the large effect of variations in cathode temperature. In a particular case, a variation of heater voltage from 4·0 to 4·7 V causes a change of output equivalent to a 10 times change of anode current. It is this sensitivity to supply voltage that has made the method difficult to use in a practical instrument.

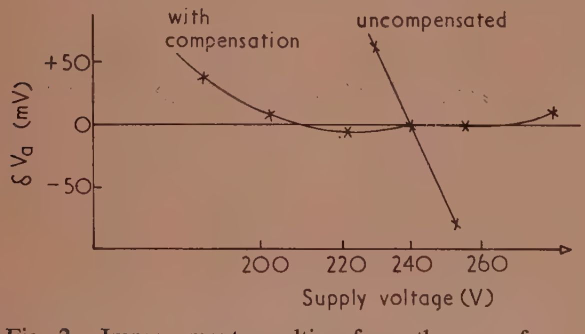


Fig. 2. Improvement resulting from the use of compensated circuit

If graphs of the logarithm of the anode current against anode voltage in the retarding field region are plotted for a range of heater voltages, a series of parallel straight lines is obtained. Thus a certain change of heater voltage can be said to be equivalent to a proportional change of anode voltage. By the use of a circuit of the type shown in Fig. 1(a fraction of the voltage supplied to the heater (rectified necessary) is used to modify the anode-cathode voltage ar so provide compensation. Fig. 2 shows the degree of cor pensation obtained.

Fig. 1(*b*) shows an arrangement suitable for use wi directly-heated diodes of the sub-miniature type, more sui able for very small currents; their $v_a - \log i_a$ characteristi appear to be linear from about 10^{-9} to 10^{-13} A.

This type of circuit cannot, of course, compensate f ageing and fatigue effects inside the diode. It is known, f instance, that the contact potentials of valve electrodes a liable to fluctuate in an irregular way; fluctuations of th sort are likely to set a limit to the accuracy of the circu described.

A densitometer using the principles described above th comprises a photoelectric cell of the vacuum type and diode, the voltage across which is measured with a suitab valve voltmeter. This valve voltmeter must be so designed have a grid current which is small compared with the smalle photocurrent to be measured; it must also be designed have adequate linearity.

Although the diode as a logarithmic device was intend for use in a direct-reading photoelectric densitometer, it h possible application to many other measurements where wide range of currents must be indicated; e.g. in work radioactivity, with ionization chambers, etc.

The method described here has only been subjected initial tests. It is being published in case other workers m wish to subject it to further examination.

Research Laboratories, Kodak Ltd., Harrow, Middlesex.

D. T. R. DIGHTON

---

* Communication No. 1715H from the Kodak Research Laboratories.

REFERENCES

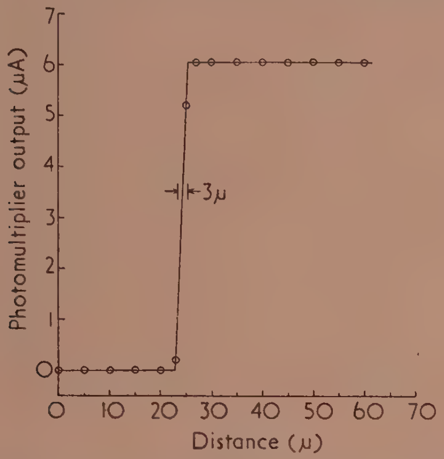
(1) MEAGHER, R. E., and BENTLEY, E. P. *Rev. Sci. Instrun* **10**, p. 336 (1939).

(2) BRIERE, M., ROGOZINSKI, A., and WEILL, J. *J. Ph Radium*, **12**, p. 144 (1951).

Adaptation of a projection microscope for microphotome

The Vickers projection microscope may be converted into microphotometer by the following simple adaptation. vertical entrance slit about 0·5 mm wide is mounted near Pointolite lamp and its reduced image focused on to specimen by a slit focusing lens which rests on the conden sub-stage. With the microscope adjusted to give a focus image of the specimen and entrance slit on the projecti screen, the required part of the specimen may be made traverse the narrow illumination field by moving the mic scope stage with the micrometer screws. The projecti screen is replaced by a photomultiplier detector assem mounted on a metal plate carrying an adjustable exit near its centre, and the system is alined so that the ima of the entrance slit falls on the exit slit. Preliminary focusi and alinement is carried out on the projection screen, a nal adjustments made with the exit slit in position by mporarily placing a small ground glass screen over it.

The intrinsic resolution obtainable depends on the magni- cation to which the microscope is set, and on the slit widths. magnification of about ×300 is the practical upper limit; ith an exit slit 0·1 mm wide, the resolution measured by anning across a razor-blade edge was then approximately μ. The figure shows this result, and makes clear the efinition of resolution in this context. Measurements of the ensity contours of electron diffraction rings on Ilford thin lm half-tone plates have been made at a magnification of 80 with a resolution of 10 μ.



Photometric scan across a sharp opaque edge showing a resolution of 3μ

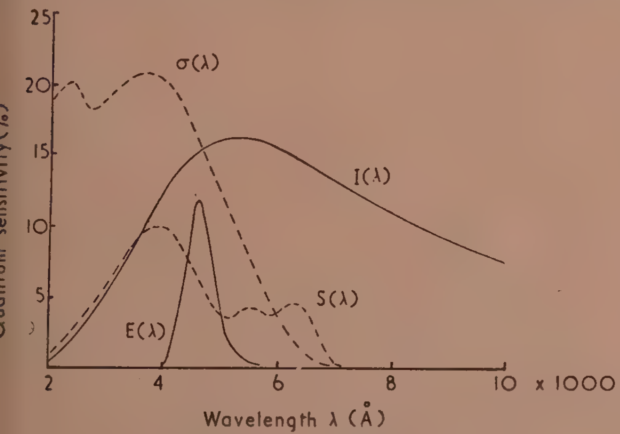
The stability of the light intensity from the Pointolite lamp, nd of the photomultiplier (type I.P. 28) were found satis- ctory when the Pointolite was operated from a constant oltage transformer, and the photomultiplier from a stabilized 0 V supply. In a test period of one hour, the photo- ultiplier output varied by less than 1%.

hysics Department, niversity of Reading.

D. H. Tomlin
F. J. Fayers

Realizable light gain in photoelectronic image intensifiers

nage intensifiers in which a focused beam of photoelectrons oduces a fluorescent image are now arousing considerable terest, particularly in astronomy where the limit of measurement is generally set by photographic sensitivity. The light gains from photocathode to fluorescent screen which have so far been reported(1–4) are, however, rather low (of the order 10 or less). As a result, the more difficult and less convenient Lallemand technique(5) of focusing the photoelectrons directly on to a photographic plate is sometimes regarded as more promising.(6) It is the purpose of this communication to point out that effective light gains of the order 100 should be achievable, using well-known materials and techniques.



The emission and response spectra.
[All functions except σ(λ) are in arbitrary units]

A high light gain clearly requires a combination of the most efficient photoelectric and luminescent surfaces. Probably the most sensitive of the former is the Sb : Cs surface, whose quantum sensitivity σ(λ) was most recently studied by Burton(7) as a function of wavelength λ and is given in the figure. Now the overall light amplification of any photoelectric device is necessarily a function of the spectral energy distribution $I(\lambda)$ of the source and, as an example, we shall consider a source of colour temperature 5400 Å, corresponding to sunlight. The function $I(\lambda)$ is plotted in arbitrary units in the figure.

As the differential probability spectrum of incident photons is now $\lambda I(\lambda)$, the mean quantum sensitivity for sunlight $\bar{\sigma}_{sun}$ will be given by:

$$\bar{\sigma}_{sun} = \int_0^\infty \lambda I(\lambda)\sigma(\lambda)d\lambda \Big/ \int_0^\infty \lambda I(\lambda)d\lambda \qquad (1)$$

and, using the curves of the figure, we find $\bar{\sigma}_{sun} \simeq 2\frac{1}{2}\%$.

Among the most efficient luminescent materials is the ZnS : Ag phosphor, which fluoresces with a blue light and was studied by Leverenz(8) and Bril and Klasens.(9) The spectral energy distribution $E(\lambda)$ of the luminescence is shown in the figure. The emission probability spectrum is, therefore, $\lambda E(\lambda)$ and the mean emission wavelength $\bar{\lambda}$ is given by:

$$\bar{\lambda} = \int_0^\infty \lambda^2 E(\lambda)d\lambda \Big/ \int_0^\infty \lambda E(\lambda)d\lambda \qquad (2)$$

Using the curve in the figure we obtain $\bar{\lambda} \simeq 4770$ Å, which corresponds to a mean photon energy of 2·6 eV.

The energy conversion efficiency of the phosphor depends on the electron energy; it increases with increasing voltage and is saturated around 25 kV.(9) Leakage currents and the possibility of breakdown impose a practical upper limit on the accelerating potential which can safely be used in an image intensifier, but potentials around 20 kV have been reported.(2–4) At this voltage the intrinsic conversion efficiency is about 25%.(9) However, because of the isotropic emission and the reflexion by the glass and by the phosphor of the luminescent radiation, only about 30% of the light is emitted in the forward direction.(9)

Bril and Klasens also investigated the effect of a thin aluminium film backing on the light output. Using a willemite luminescent screen and a 20 kV accelerating potential, they found a maximum improvement of 2·2 for a backing thickness of 0·08 μ. The exact reflecting thickness was not critical and it is probably not unreasonable to suppose that similar results would hold for the ZnS : Ag phosphor.

The mean number of photons emitted per incident electron is therefore:

$$(20\,000/2{\cdot}6) \times 25\% \times 30\% \times 2{\cdot}2 \simeq 1300$$

so that the total light gain in the intensifier is $1300 \times 2\frac{1}{2}\% \simeq 32$. However, the spectrum of the emitted light has a strong peak in the blue region, so that, if the image is to be received on a photographic plate, there is a further gain factor g due to the greater sensitivity of a fast emulsion to blue light. The spectral energy sensitivity $S(\lambda)$ of a typical fast panchromatic emulsion$^{(10)}$ is shown in the figure. The factor g is clearly given by:

$$g = \frac{\int_0^\infty S(\lambda)E(\lambda)d\lambda \Big/ \int_0^\infty E(\lambda)d\lambda}{\int_0^\infty S(\lambda)I(\lambda)d\lambda \Big/ \int_0^\infty I(\lambda)d\lambda} \qquad (3)$$

and, using the curves in the figure, we find $g \simeq 2{\cdot}74$. The *effective* light gain for photography is now $32 \times 2{\cdot}74 \simeq 90$, for a source having the spectral distribution of sunlight.

The foregoing assumes, of course, that there is a 1 : 1 electron optical magnification and that the photographic plate is placed immediately behind the fluorescent screen. However, as the latter must be deposited on glass thick enough to withstand atmospheric pressure, there will be an appreciable loss of definition. This can be avoided by using a lens system to focus the luminescent image on the plate, but only at the cost of a considerable loss of light.

The introduction of a lens system permits adjustment of the final image size, but the choice of the optimum magnification is a somewhat controversial question. The fraction α of the isotropically emitted light reaching the image formed by a lens of relative aperture F is given by geometrical optics as:

$$\alpha \simeq \epsilon a^2 F^2/8(1+a)^2 \qquad (4)$$

where a is the magnification and ϵ the transmission co-efficient. While α is greatest for large a, the photon density—and hence the photographic speed—is proportional to $1/a^2$, so that considerable demagnification appears to be desirable. However, it is preferable to introduce any optical demagnification between the telescope and the image intensifier, where the light is relatively collimated. While it would be better still to demagnify the electron optical image in the tube, where there is no energy loss, this calls for an electrostatically focused tube with its attendant aberrations.

Taking $\epsilon \simeq 80\%$ and $a = 1$ in equation (4) we find, for an $f/1$ lens, $\alpha \simeq 2\frac{1}{2}\%$. This is very low, but two equal $f/1$ lenses placed end to end give $\alpha \simeq 8\%$. The effective photographic gain of the complete instrument is therefore $90 \times 8\% \simeq 7$.

Let us now consider a cascaded arrangement of two intensifiers separated by a pair of adjacent $f/1$ lenses which forms an image of the first screen on the second photocathode. Because the mean quantum sensitivity $\bar{\sigma}_{ZnS}$ of the second Sb : Cs surface is very high for the blue emission of t ZnS : Ag screen, the overall effective gain now exceeds t square of 7. From the curves in the figure we find:

$$\bar{\sigma}_{ZnS} = \int_0^\infty \lambda E(\lambda)\sigma(\lambda)d\lambda \Big/ \int_0^\infty \lambda E(\lambda)d\lambda$$
$$\simeq 15\tfrac{1}{2}\%.$$

If a further pair of lenses focuses the second luminesce image on the plate, the overall effective gain is now:

$$2\tfrac{1}{2}\% \times 1300 \times 8\% \times 15\tfrac{1}{2}\% \times 1300 \times 8\% \times 2{\cdot}74 \simeq 11$$

Thus, an appreciable gain is realizable with the final ima conveniently focused on the plate. If it were possible dispense with the intermediate lens system, for example depositing the first fluorescent screen and the second pho cathode on opposite sides of a thin glass membrane, t figure would rise to 1400.

These estimates suggest that the technique of image tensification is not without promise when compared with t more difficult and less permanent methods of Lallemand.

This work was supported financially by a grant from t Ministry of Supply.

Imperial College of
Science and Technology,
London, S.W.7.

L. Mandel

REFERENCES

(1) Krizek, V., and Vand, V. *Electronic Engng*, **18,** p. 3 (1946).
(2) Teves, M. C., and Tol, T. *Philips Tech. Rev.*, **14,** p. (1952).
(3) Fenner, E., and Schott, O. *Z. Angew. Phys.*, **6,** p. (1954).
(4) Eckart, F. *Ann. Phys.* [*Leipzig*], **14,** p. 1 (1954).
(5) Lallemand, A., and Duchesne, M. *C.R. Acad. S* [*Paris*], **233,** p. 305 (1951).
(6) Hiltner, W. A. *Astron. J.*, **60,** p. 17 (1955).
(7) Burton, J. A. See Zworykin and Ramberg, *Pho Electricity*, 1st Edition, p. 59 (London: Chapman a Hall, 1949).
(8) Leverenz, H. W. *Proc. Instn Radio Engrs*, **32,** p. 2 (1944).
(9) Bril, A., and Klasens, H. A. *Philips Res. Rep.*, p. 401 (1952).
(10) Tupper, J. L. See Mees, *The Theory of the Photograp Process*, 2nd Edition, p. 853 (New York: Macmill and Co., 1954).

New instruments, materials and tools

e Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improved oducts. The Institute of Physics assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

nall analogue computer. Saunders-Roe Ltd. (Electronics Division), Osborne, Isle of Wight.

e Miniputer, a small analogue computer, is capable of lving linear differential equations having time as the lependent variable. Repetitive operation is used with uble-trace cathode-ray tube display. This has the advantage at the effect of changes of parameter are immediately ible. The computer contains the following units:

(*a*) Ten amplifiers, each having a gain of 1500 with 3 dB point at 12 kc/s and short-term drift about 10 mV. These are each combined with a similar amplifier having 1 : 1 feedback so as to produce an output with reversed sign.
(*b*) Twenty coefficient potentiometers calibrated with an accuracy of 0·7%.
(*c*) Double-beam cathode-ray tube display having sweep times of 10, 20 or 40 ms. Each trace can be switched to the output of any amplifier.
(*d*) Ten valve clamps which can be connected across any computing capacitor for automatic discharge between scans.
(*e*) A patch panel for setting up problems by plugging in connecting links and passive components.

s an example of the accuracy, the makers state that the mputing error introduced by a summing amplifier having e inputs and an external gain of 10 on each is 1·3%.

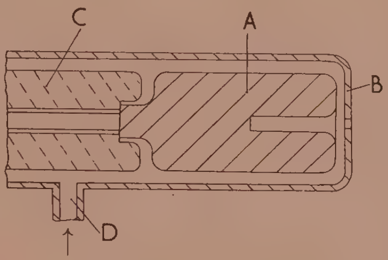
igh-speed vibration mill. Research and Industrial Instruments Co., 12 Marlborough Yard, London, N.19.

his high-speed vibration mill for grinding small quantities powder in a short time consists of an electromagnet which energized from the 220–250 V a.c. mains supply. A ring blade, carrying a capsule at its free end, is clamped front of the magnet and is so chosen and shaped that it sonates in the oscillating magnetic field. With a 50 c/s ains supply the blade vibrates at 100 c/s. The capsule con- ins the powder and one or two small spheres. It is supplied ther in tool steel, with chromium-plated ball bearings or mpletely in agate as required; both types having internal imensions of ⅜ in. diameter and a length of approximately in. The agate set produces cleaner powders.

n ionizing unit for discharging non-conductive specimens in an electron diffractograph. Trub, Tauber and Co. A.G., Zürich, Switzerland.

he examination by reflexion of electrically non-conductive ecimens by electron diffraction is often hampered by the egative charges which settle on the surface under examina- on and repel the beam. This effect may be countered by rongly ionizing the space surrounding the specimen, i.e. by nizing the remaining traces of gas, so that the charges are eutralized by recombination as soon as they settle. In rinciple any method of ionization can be used, but experience ows that a powerful ion bombardment is needed to ensure atisfactory results under all circumstances.

An ion source meeting these requirements has been devel- ped for use with the Trub, Tauber electron diffractograph nd has an output sufficient to cope with any charge. This evice employs the Induni cold cathode principle (British atent No. 603088), as used for the beam of the diffractograph self. The polarities are however reversed, the solid anode *A* (see figure) being closely surrounded by the cathode *B*. Opposite the aperture in the cathode is a depression in the anode. Depending on the depth of this depression the ions are generated either on the metallic base of the depression itself or in the gas between the cathode aperture and the anode; and they escape through the cathode aperture in a narrow stream. This arrangement results also in evacuation of the space between the anode, the cathode and the insulator *C*. An air leak valve at *D* provides for adjustment of the gas pressure and, thereby, of the discharge current, so that the latter can be maintained constant during operation. This form of valve, which is used for the discharge tube of the diffractograph itself in the same way, affords fine adjustment of the current between values of 0 and 1 mA, at pressures of 2–3 000 V.



Source of powerful ion bombardment

The complete ionizing unit, with attached leak valve, is mounted laterally on the diffractograph so that the ion stream does not strike the surface under examination but grazes the latter. This is an important feature because ion impingement on the surface would result in slow but definite etching. If, on the other hand, it is desired to use the ion bombardment for etching, in the examination of metals, for example, the ion stream may be directed normally on the surface. A higher voltage is needed to give rapid etching. Adjustment of the space between the anode and the cathode enables the ionizing unit to be operated at potentials up to 50 000 V.

Painted circuit kit. S. Sterling Co., Detroit, Michigan, U.S.A. (U.K. agent: L. Brooke Edwards, 25 Palmeira Avenue, Hove, 3.)

In wiring an electric strain gauge or other transducer on a rotating shaft to the recording instruments, a slip-ring assembly must be employed, and usually this has to be specially constructed. The model 501 slip-ring kit makes it possible to brush-paint the slip rings over an insulating enamel. The assembly is baked and polished. The resulting surface has a sufficiently low contact resistance, and is hard enough, to be suitable for strain gauge circuits. With soft carbon brushes, the slip rings can be run at speeds up to 700 ft/min. Connexion of the strain gauge to the slip rings is easily made by painting. A band of silver paint is applied axially on the shaft from the far ring to the position of the gauge. A second coat of enamel is applied over this band and on this the near slip ring is painted, together with a second paint band running to one lead of the gauge, which is mounted on top of the enamel insulation covering the first band of paint. The complete kit contains silver paint, paint brushes, carbon brushes, solvent, enamel and polishing materials. The kit can obviously be used for constructing "printed circuits."

Notes and comments

Length of papers for publication

The Editor believes that the view is widely held in some laboratories that papers exceeding 3000 words cannot be considered for publication by The Institute of Physics in either this or its other Journal (*British Journal of Applied Physics*). This is not so. Indeed, papers of nearly double this length have recently been published. To be acceptable, however, papers must be as concise as clarity allows.

Exhibition of X-ray photography

A selection of X-ray photographs will be exhibited at The Royal Photographic Society's house, 16 Princes Gate, London, S.W.7, from 13 to 22 December. In addition, ciné films will be shown and several lectures have been arranged. The exhibition will be opened by Mr. W. E. Schall at 4.30 p.m., and at 7 p.m. Mr. Schall and Mr. Cuthbert Andrews will speak on the development of X-ray photography in industry and medicine.

The final date for the receipt of entries is 4 November; entry forms are available from the above address.

Proceedings of the Geneva conference on peaceful uses of atomic energy

The United Nations have announced that the proceedings of the international conference on the peaceful uses of atomic energy, held in Geneva in August 1955, will be published in sixteen volumes of approximately 500 pages each. There will thus be available the complete, unabridged record of the conference which will comprise all papers, whether presented orally or in written form, together with a record of the discussions on each paper.

These volumes will be published in several languages; the English edition will be available in the beginning of 1956, the others at a later date.

The pre-publication price will be £39, 418 guilders or the equivalent in other currencies for the full series of sixteen volumes. Advance orders must be received before 31 December, 1955. Orders for the full set of sixteen volumes or for individual volumes (the prices of individual volumes will be announced later) may be placed with any sales agent for United Nations publications including H.M. Stationery Office, P.O. Box 569, London, S.E.1, and N. V, Martinus Nijhoff, Lange Voorhout 9, The Hague, Holland.

Mimeographed copies of most of the individual papers read at the conference are now available at 1*s*. 9*d*. each, 1.00 guilder or the equivalent in other currencies. Orders for individual papers, giving the full title and author, may be ordered through H.M. Stationery Office or through N. V. Martinus Nijhoff. These agents do not carry stocks of the individual papers but will forward orders to the European Office of the United Nations for execution and will acce
payment for the papers in national currencies.

Semiconductor symposium

The Fourth Annual Semiconductor Symposium of t
Electrochemical Society will be held from 29 April to 3 Ma
1956, at the Mark Hopkins Hotel in San Francisco, Californ
At present it is planned to include two half-day sessions
semiconducting materials, elemental alloys and compoun
a half-day session on surface-controlled phenomena; and
half-day session on chemical process technology. It is hop
to present a balanced agenda including one review paper
the state of each field, 30-minute presentations (includi
discussion time) of new information which can be schedu
by mid-winter 1955, and a number of shorter presentatio
of about 10 minutes' duration of the "late news" type.

Persons wishing to present papers are requested to sub
to the Chairman the titles of proposed papers as early
possible and no later than 15 November, 1955; submit
abstract of approximately 75 words no later than 15 Janua
1956; and submit a second "extended abstract" of ab
1000 words with brief pertinent data, illustrations, curv
etc., not later than 1 February, 1956.

Persons wishing to present 10-minute "late news" type
papers are requested to notify the Chairman as soon
possible, giving relevant details and submit 75-word abstra
no later than 8 April, 1956.

The Chairman is J. W. Faust, Jr., Westinghouse Resear
Laboratories, Beulah Road, Churchill Borough, Pittsburgh
Pennsylvania, U.S.A.

Erratum

In the description of an internal brake motor on p. 1
of the May issue of this *Journal* the units of torque
incorrectly represented as oz/in. These should, of cour
have been oz. in.

British Journal of Applied Physics

Contents of the October issue

ORIGINAL CONTRIBUTIONS

The diffuse reflexion of silver atoms at a metallic target at high temperat
By S. Chomet and J. Yarwood.

Air circulations about a vibrating plate. By M. D. Waller.

Plastic flow in coal. By P. C. Newman.

The determination of the order of interference in white light. By R. C. F
and H. J. Marrinan.

The use of electronic analogue computers with resistance network analog
By W. J. Karplus.

The permittivity of two phase mixtures. By C. A. R. Pearce.

Transient heat conduction in multiphase media. By J. H. Weiner.

Measurement of metallurgical equilibria by thermal conductivity gas analy
By J. W. Evans.

An X-ray method for studying radial current distributions in electron be
By J. S. Thorp.

A thermally triggered spark gap. By T. E. Broadbent and J. K. Wood.

Initiation of hot-cathode discharges. By N. R. Daly and K. G. Emeleus.

NOTES AND NEWS

New books — Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principles, construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Square, London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation of contributions*. (Price 2*s*. 6*d*. including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon application from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, London, E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within 60 days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of address or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £4 per volume ($11.50 U.S.A.), including index (post paid) payable in advance. Single parts, so far as available, may be purchased at 8*s*. each ($1.15 U.S.A.), post paid, cash with order. Orders should be sent to The Institute of Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

SPECIAL ARTICLE

Electronic computing machines and their uses

By J. H. Wilkinson, M.A., National Physical Laboratory, Teddington, Middlesex

The two main classes of computing machines, digital and analogue, are defined and a short history of machines of the digital class is given. The basic principles of design of the electronic digital computers which followed ENIAC are described and this is followed by an introduction to the elements of programming for the new machines. The article concludes with some of the types of computation arising in physics and engineering for which the machines are suitable.

ore describing electronic computing machines it is useful consider computing machines in general. There are two in classes of computing equipment known respectively as alogue and digital machines. In analogue machines mbers are represented by physical quantities such as the gular rotation of a shaft or the current in a resistor, the mbers being the measures of those physical quantities. amples of analogue machines are the slide rule, the plani- ter, the differential analyser and resistance network alysers. Because they are dependent on the accuracy of ysical measurements, analogue machines are strictly ited in regard to the precision of which they are capable. en with a well-designed planimeter, for example, it is ficult to calculate areas to more than four significant ures. For most physical problems this does not constitute severe restriction and a far more serious limitation of alogue machines is that they are, in general, special purpose vices. A planimeter, for example, can only be used for ding areas or at most, in its more general form, volumes d moments of inertia of solids of rotation. It is useless, example, for solving differential equations or finding the e periods of vibration of a mechanical system.

Digital machines, on the other hand, work directly with mbers in digital form and are capable of performing actly the fundamental operations of arithmetic, addition d subtraction, and usually also multiplication and division, hough on some machines the two latter operations may ve to be carried out by means of a sequence of additions d subtractions. Examples of digital machines are the ding machines used for accounting, desk calculating chines such as the Brunsviga hand machine and the archant electrical machine, and the standard punched card chines. Whereas the power of an analogue machine rings mainly from its specialization which has the result at it performs the calculation for which it was designed ickly and efficiently, the value of a digital machine arises entially from its lack of specialization. With an ordinary sk calculating machine we can solve any problem which n be reduced to a sequence of arithmetic operations, and s means, in particular, by means of the calculus of finite ferences, we can solve ordinary and partial differential uations and integral equations. It is perhaps in order to nsider precisely what is meant by solving such problems merically. In the standard textbooks on differential uations, an equation is regarded as soluble if the solution n be expressed in terms of a closed formula independent whether it is practicable to evaluate that formula numeri- ly for specific values of the argument. A differential uation is solved numerically, on the other hand, by pro- cing values of the independent variable at a set of values of the dependent variable usually at regular intervals in the latter. It is usual to think of an analytical solution as "exact" and a numerical solution as "approximate," though from the point of view of the physicist or engineer who wishes to make use of the solution, the difference between the two is illusory. To make use of a closed formula he must evaluate it, and as soon as he does this he must work to a finite number of figures. Provided the numerical method of solution is of the type that any preassigned accuracy is attainable (and usually this is true) then the numerical solution has as much right to be regarded as "exact" as the closed formula. From what has been said it is clear that, from a theoretical point of view, all digital machines are equivalent, in the sense that a problem which may be solved on one may be solved on any other, or indeed with a pencil and paper and a knowledge of the multiplication table. The only thing which restricts the power of a given digital computer in practice is its ability to carry out a computation in a reasonable period of time without employing prohibitive man-power. For example, the solution of a hundred simultaneous linear algebraic equations with no zero elements is more than a year's work on a desk machine, even for a skilled operator, and is therefore virtually insoluble.

A SHORT HISTORY OF AUTOMATIC COMPUTERS

In order to extend the practical range of application of a digital computer beyond that of the hand operated desk machine, two main developments are required which are to a large extent complementary. First the speed at which the basic arithmetic operations may be carried out must be increased and secondly, and this is at least as important, the machine must be capable of carrying out long sequences of operations without human intervention. The second is necessary because if the result of each unit operation had to be written down, or even typed on paper, an increase in the speed of carrying out the arithmetic operations beyond a certain limit would be immediately dissipated. The idea of building such a machine is by no means of recent origin. In the last century a machine known as the Analytic Engine was designed by Charles Babbage.(1,2) Although it was conceived in purely mechanical terms, in many respects it anticipated the modern electronic computer. With the advent of electronic pulse techniques the design of automatic computing machines received fresh impetus and the first purely electronic computer was completed during the second World War at the Moore School of Electrical Engineering, Pennsylvania. The machine was called ENIAC or Electronic numerical integrator and calculator. ENIAC proved surprisingly reliable in spite of the fact it contained about

18 000 valves, and it achieved speeds of computation which were of a different order from what had been possible before. An indication of this speed can be gained from the fact that the multiplication of two ten-digit decimal numbers took about two milliseconds. Immediately after the war the construction of electronic computing machines was started at a number of research centres both in the U.S.A. and in this country. Although these machines differed substantially in detail they had very much in common as regards their logical structure and all of them were an advance on ENIAC in one important respect which will be described later. They also contained a very much more modest number of valves varying from about 1000 to 3000 in the earliest successful machines. The first electronic computer of the new type to carry out a computation was the machine built by the Electrical Engineering Department of the University of Manchester. It was brought into operation on simple calculations in the summer of 1948.(2) Although it was merely an experimental machine with very limited facilities it demonstrated the practicability of these machines. It was followed in the summer of 1949 by EDSAC(3) (Electronic delay storage automatic calculator) built at the Mathematics Laboratory, Cambridge. This was the first machine on which serious computation was achieved and much of the pioneer work on their use was carried out on EDSAC. This work still forms the basis of the system of operation used on most existing machines. The first successful machine in the U.S.A. was SEAC (South-eastern automatic computer) built at the National Bureau of Standards, Washington. It performed its first calculation in May 1950 as did also the Pilot ACE(4) (Automatic computing engine) constructed at the National Physical Laboratory, Teddington. These two machines were probably the first to do successful computation on a production basis. SEAC has been used for much of its time on a twenty-four-hour day and the Pilot ACE on a thirteen-hour day. These early machines were modified from time to time in the light of experience in using them and it is interesting that engineered versions of all three of the British machines have since been produced. Machines built on the basis of the Manchester machine, though with considerable extensions, have been produced by Ferranti Ltd. and are known as the Ferranti Mark I and Mark I* computers.(5) A machine, LEO, based on the EDSAC design has been built by J. Lyons and Co.(5) and has been used extensively, mainly for clerical purposes, but also for some scientific calculations. Further machines of an improved design are planned by the same company. Engineered versions of the Pilot ACE have been built by the English Electric Co. under the name DEUCE(5) (Digital electronic universal computing engine) and there are already three of these machines in operation. At a recent conference in this country no fewer than twelve firms described machines which were available or would be available in the near future. In the U.S.A. there are already so many different electronic computers on the market that it would take more space than is available for the whole of this article to give a brief description of each of them. In the last two years the emphasis has shifted a little from machines intended for scientific work to machines intended for the commercial field. Although the requirements are somewhat different this development is certain to be advantageous to the scientific user in the long run, in that it will encourage research into the development of machines of great reliability and will also, because of the greatly increased market, lead to a reduction in price.

In addition to building machines, several of the firms intend
to set up computing services with staff which will under
to do computing for customers, both in the scientific
commercial fields. For a user who has not sufficient wor
justify the purchase of a machine, this will provide an op
tunity for assessing the value of a computer in his fiel
work.

LOGICAL DESIGN OF AN ELECTRONIC COMPUT

All the electronic computers which have been built s
the completion of ENIAC may, in a general sense, be
to have the same logical design, and they consist of five
parts.

The first part is an arithmetic unit which is capabl
performing the fundamental arithmetic operations at a
high speed. In the early machines this unit could
subtract and multiply, but division was performed by m
of a series of the other operations. Most of the more re
machines, however, have an arithmetic unit which is cap
of performing division as a unit operation.

The second part of a computer is the store or mem
which holds the numbers which form the initial data or
at the intermediate stages of a computation. The sto
divided up into a number of registers each of which h
one number, the numbers stored in any given machine b
of a standard length, usually from nine to twelve deci
Small numbers will therefore have zeroes in the more signifi
positions, while very long numbers will occupy more
one register. Each of the registers in the store is giv
serial number which is usually called its "address."
order to take advantage of the high speed of computa
it is essential that this store should be capable of provi
the operands involved in arithmetic operations at a s
comparable with that of the operations themselves.

The speed of the arithmetic unit would still be waste
the machine had to be directed to carry out the arithm
operations, one by one, by a human operator. There
therefore be some provision for carrying out long seque
automatically. On the ENIAC this was achieved by m
of a vast system of plugs, cables and hand switches w
were used to make interconnexions between the various
of the machine in a manner appropriate to the computa
in hand. Making these interconnexions was a time-cons
ing process and one in which errors were likely to be m
which had to be eliminated by careful checking and trial
of the computation. Moreover, if further runs of the s
problem were required at some later time after the mac
had been plugged up for another problem, the whole pro
had to be done again. In nearly all subsequent machine
entirely different system is employed. If we conside
typical operation of which a machine is capable it migh
described as: "take the number in register number A, a
to number in register number B and store the resul
register number C." This may be represented symbolicall

$$A + B \text{ to } C.$$

Similarly we shall have the operations

$$A - B \text{ to } C$$

and $$A \times B \text{ to } C$$

and for further economy the word "to" may be omitted.

Now the addresses A, B and C are themselves numbers
if we assign numbers to each of the arithmetic operat

ing 0 for addition, 1 for subtraction, 2 for multiplication en the set of numbers

125, 2, 136, 257

r example, could specify, "multiply the number in register 5 by the number in register 136 and send the result to gister 257." The coded operation above contains ten cimal digits and could be stored in a ten-decimal digit gister just like an ordinary number. The registers in an ctronic computer are of the type that when a number is nt to one of them, the number previously held by that gister is destroyed and replaced by the new number. The ntent of any register may, however, be used as one of the erands in an arithmetic operation without being destroyed. uring the course of a computation each register will hold any different numbers. Before a computation starts, a scription of the arithmetic operations which are to be rformed is stored in the coded form in some of the registers the machine. In general, any of the registers may store her a number or a coded "instruction." It is useful to ve a name which can be applied to the contents of a register dependent of whether it is a number or an instruction. ch register is said to contain a "word." A most important ature of the coded representation is that arithmetic operans may be performed on the instructions themselves, and is mainly due to this fact that the new electronic computers ve their great flexibility. In addition to instructions which ecify the arithmetic operations a further type of instruction needed in order to achieve this flexibility. The need for is will appear when a specific example is considered and it ll be described then. The third part of a computer is the ontrol" unit. This takes the coded instructions in the rrect sequence and causes them to be obeyed. The code hich has been described above is called a "three-address de" because each instruction specifies three different ldresses. It is perhaps the most natural code to use for troductory purposes but it should be mentioned that ere are many different types of codes used on existing achines.

Inside the machine the numbers and instructions are ored as electronic pulses, small magnetic dipoles in magnetic aterial or in some similar manner. A problem must be fed to the machine, however, in a form in which it can readily prepared by human operators. The fourth part of an ctronic computer is the unit which does this, and it is lled the "input." On most existing machines the input nsists of a reader which will convert information which is inched either on cards or on paper tape into the pulse rm with which the machine operates internally. Both the ta and the coded numerical instructions are fed into the achine by means of this input.

Finally the results of a computation are needed in a form hich can be recognized and used by the operator. The th part of the machine, therefore, is an output unit by eans of which final answers, and sometimes intermediate sults, are communicated to the outside world. The most mmon forms of output are punched card or punched tape uipment and electrically-operated typewriters. The most nvenient form of output is decided partly by the use which to be made of the results and partly by time considerations. for example, the output is to be used by some other equipent (not necessarily a digital computer), the best form of tput is on the input medium of that equipment. If the sults are to be used directly by human operators it may ll pay to produce them on punched cards because this can done more quickly than typing directly from the machine. The punched cards may then be used to obtain printed results without wasting the time of the electronic computer.

THE FUNDAMENTAL PRINCIPLES OF THE PREPARATION OF A PROBLEM FOR AN ELECTRONIC MACHINE

When an electronic computer of new design is first completed it is not immediately of value for serious computation. It cannot as it stands perform the simplest calculation, such as extracting the square root of a number. Before such a calculation can be done on the machine it has to be broken down into a number of simpler operations consisting of a sequence of additions, subtractions and multiplications, and divisions if the machine has division as one of its basic operations. It will be found that something like ten instructions are needed to extract a square root. These instructions have then to be represented in the coded form appropriate to the machine and finally punched up on the input medium. The process of devising the appropriate sequence of operations for a computation is usually known as "programming," and that of producing the precise set of coded instructions, as "coding," though both terms are used somewhat loosely. At first sight it would appear that since one instruction specifies one operation only, a computation such as solving a hundred linear algebraic equations, which involves about one-third of a million multiplications, would need a corresponding number of instructions, so that programming it would be a prohibitive task. However, this is not so because computations do not consist of a long sequence of unrelated operations, but rather of a number of comparatively small sequences of operations which are repeated a large number of times, using different operands each time. To take advantage of this, electronic computers have, in addition to arithmetic instructions, others which enable the machine at any stage in a computation to decide which of two sequences of instructions it will obey next, the decision being taken by means of some arithmetic criterion. On machines with an instruction code of the type already described consecutive instructions obeyed will normally be stored in registers having consecutive addresses. In such a machine bifurcations may be achieved by an instruction specifying three addresses A, B and C which does the following. "If the number whose address is A is less than the number whose address is B, take the next instruction from the register whose address is C, otherwise proceed as usual with the next instruction in sequence." An instruction of a similar nature is included in all electronic computers, the decision usually being taken by examining the sign of a number (in the above example the sign of the difference of the numbers in registers A and B) or the zero or non-zero nature of a number or of some one digit of a number. A simple example will serve to illustrate the value of an instruction of this type and also of the ability to modify instructions by carrying out arithmetic operations on them. Suppose we have a sequence of n numbers stored in registers 100 to $100 + (n - 1)$ and we wish to multiply all these numbers by k and store the results in the same registers. We shall assume that k is stored in register number 0, n in register number 1 and the number 1 in register number 2. Register number 3 originally contains zero but as the calculation progresses, it holds the numbers 0, 1, 2 up to n, in succession. Register number 4 holds a word consisting of a 1 in the positions occupied by the first and third addresses of an instruction. It is never obeyed as an instruction but is merely used to modify another. The short programme needed to effect the computation is in registers 5 to 8 and the programme which is to be obeyed when the current one is complete is stored in registers 9 onwards. The contents of the various registers are given below.

Number of register	*Word stored*
0	k
1	n
2	1
3	0 (originally, but modified later)
4	1, 0, 0, 1 (used to modify instruction in 5)
5	100 × 0 100 (originally, but modified later)
6	5 + 4 5
7	3 + 2 3
8	3 F 1 5
9	Subsequent calculation.

The first instruction to be obeyed is in register 5. This takes the first of our sequence from register 100, multiplies it by k, the number in register 0, and puts the result in register 100. The next instruction is in register 6. This takes the word in register 5 and adds it to that in register 4 and puts the result in register 5. This has the effect of modifying the instruction

$$100 \times 0 \quad 100 \text{ to}$$
$$101 \times 0 \quad 101.$$

The next instruction is from register 7. This has the effect of adding 1 to the number stored in register 3 so that this number changes from 0 to 1. The next instruction is from register 8. This is our special operation which I have denoted by F. It takes the number in register 3, which is by now equal to 1, and if this is less than the number n in register 1, the next instruction is taken from register 5. Otherwise the next instruction is taken from register 9. If n is a large number this means that we return to the instruction in register 5. This instruction has been altered since we obeyed it last and it now has the effect of multiplying the second of our numbers, that in register 101 by k. The instruction from 6 then modifies it further to

$$102 \times 0 \quad 102.$$

Similarly, the second time it is obeyed, the instruction from register 7 changes the number in register 3 from 1 to 2. It will easily be seen that the four instructions in registers 5 to 8 will be obeyed n times, by which time register 3 will contain the number n, so that on the nth occasion when the instruction from register 8 is obeyed it finds that the number in register 3 is no longer less than the number in register 1 and the machine proceeds with the instruction in register 9. The number of instructions needed is not dependent on n, but n determines the number of repetitions of the set of four instructions. This simple example is typical of programming in general. One point should be noticed. The computation could have been coded directly using the instructions

$$\begin{array}{c}100 \times 0 \quad 100\\ 101 \times 0 \quad 101\\ 102 \times 0 \quad 102\\ - - - - - - -\\ (100 + n - 1) \times 0 \quad (100 + n - 1).\end{array}$$

If this had been done, n instructions would have been needed, but the calculation would have been faster. In the direct programme there is only one instruction per multiplication whereas in the more sophisticated programme there i cycle of four instructions per multiplication. The mach spends a good deal of its time on organizational instructio concerned with counting and modifying other instructio On the other hand it is a general programme, in that putting the appropriate value of n in register number 1 number of quantities may be dealt with. In the ab example the number of repetitions of the sequence of ope tions was determined in advance. However, this need be so. We may be calculating a quantity by an iterat method and wish to repeat a cycle of instructions until values obtained in two successive repetitions differ by than a preassigned quantity. Our special operation clearly deal with this requirement. Because of the repeti nature of the computation the programme for solving linear algebraic equations in n unknowns requires co paratively few instructions and their number is independ of n. The number n only affects the number of times e instruction is obeyed either in its original or in its modi form. On the Pilot ACE, for example, the general program requires about 320 instructions and the greater part of th are due to special considerations which arise in maintain accuracy in the solution of this particular problem.

In spite of this, programming would still be a prohibi task if each problem has to be programmed completely *initio*. This is avoided by preparing a number of stand sets of instructions which enable the machine to carry most of the more basic elements of computation. These of instructions are known as "subroutines" and they punched up on the input medium and stored in the "libra associated with the machine. For example, the extraction the square root of a number is a frequently occurr operation. If a computation involves a square root, the copy is made of the library subroutine for extracting a squ root and included in the programme for that computati Special techniques have been developed to simplify incorporation of subroutines into main programmes.(6) would be out of place to consider these in detail here, bu brief indication of the form of a subroutine, and the proble involved in its use should suffice. The specification o typical subroutine may be illustrated by that for a square r Such a subroutine will consist of a set of instructions wh is such that, given a number in a specified register the the instructions are obeyed, the square root is produced some other specified register. Frequently the main p gramme for a computation will need to make use of the sa subroutine at more than one stage during its execution. would be uneconomical to have more than one copy of subroutine in the store, and accordingly provision is m so that the main programme can select the first instructio a subroutine as the next to be obeyed, and also make p visions that when the subroutine is completed the mach will return to the correct point in the main programme.

The more a machine is used, the more extensive beco the library of subroutines and of basic programmes associa with it, and in effect the machine grows progressively m powerful. Once a computation has been programmed coded the machine can be made to carry out any spe application of that programme merely by punching up appropriate data. Thus on the Pilot ACE (and many o electronic computers) in order to solve a set of linear equati we merely have to punch up the coefficients in the equati and feed them into the machine together with the exis programme. There is no need for any further programm In assessing the value of a given machine the range and sc of existing subroutines and programmes prepared for it i tal importance, particularly of those programmes which lie the field of interest of the user. The last point is important ecause, for example, a very extensive library of subroutines ppropriate to scientific computations will not usually be of uch value to a user who wishes to employ a machine for ommercial work. There is also an advantage in having a achine of which there is more than one copy, since this eans that the task of producing programmes will be shared ith others.

COMPUTATIONS SUITABLE FOR ELECTRONIC COMPUTERS

From what has been said above it is clear that we can sily decide what computations can be done on an electronic omputer. The answer is, any problem for which a numerical ethod of solution consisting of additions, subtractions, ultiplications and divisions can be devised. However, not l such problems are suitable. At one end of the scale we ould not use an electronic computer to multiply two umbers together. The two numbers would have to be unched on cards or tape and it would be quicker to use a esk calculator. At the other end of the scale we could not olve a set of 100 000 linear equations. The fastest existing achine is still many times too slow. These might be regarded s fairly trivial observations but it is clear from the problems hich are sometimes brought for solution that neither of them universally appreciated even by practical physicists and ngineers. Problems have been presented for which it would ke hundreds of years to print all the results on paper. ime of computation is still not a consideration which can e neglected but unfortunately it is difficult to give a guide the time which a computation will take. The times taken r a few specific calculations on the Pilot ACE will perhaps ve some idea of the scale.

Evaluation of the cosine of an angle, 20 ms.

Calculation of an exponential, 40 ms.

Extraction of a square root, 16 ms.

Solution of a set of thirty linear algebraic equations, 90 s oes not include reading in the data or punching the answers).

Calculation of the complex zeroes of a polynomial of order 2 with complex coefficients, 2 min.

Computation of the trajectory of a shell. Points on the ajectory calculated at a speed which is of the same order as e time taken by the projectile to reach these points.

ne above times are approximate only and may vary a tle with the specific example. The fastest existing machines the U.S.A. may improve on some of these times by a factor 10. Many of the slower machines will exceed them by a ctor considerably greater than 10.

An important consideration is the size of store which is eded for a problem. Thus the time taken to solve a set of ear equations varies as the cube of the number of equations til the size of the matrix involved exceeds the storage pacity of the machine, when a different approach has to used and the time accordingly shows a discontinuity at is point.

Even if the time which a computation will take on a machine reasonable it may still not be suitable. A certain amount effort will be needed to programme it, unless it is identical th a basic programme, and this may not be worth expending t is a single isolated computation. If the same computation needed repeatedly however, for different values of some rameters involved, then the labour expended in the programming will be gradually recouped. The preparation of a programme to do a specific computation may be said to replace the construction of an analogue machine for that problem.

Again a few specific examples may help to give some idea of suitable types of computation.

The calculation of shell trajectories for various types of shell is an almost continuous requirement of the Service Ministries for the preparation of range tables. The mathematical formulation of the problem is the solution of the pair of differential equations

$$\ddot{x} = -C v \dot{x} P(v) f(y)$$
$$\ddot{y} = -g - C v \dot{y} P(v) f(y)$$

where x, y are the horizontal and vertical co-ordinates of the shell, C is a constant which depends on the size and shape of the shell, v is its velocity, $P(v)$ is an empirical function of the velocity and $f(y)$ represents the density of the air at height y. The values of x, y and v are needed at equal intervals in time, usually of the order of a second, throughout its flight. The computation of a single trajectory can be completed on a desk machine in a time which is of the order of a day or two, depending on the type of shell. However, it is a three-parameter problem since trajectories are needed for a range of values of C, a range of muzzle velocities and a range of angles of fire. Moreover, the empirical function $P(v)$ is not fixed for all time, but is changed occasionally as a result of further experiments. This makes the problem sufficiently formidable for the use of an electronic computer to be considered. Now the solution of sets of ordinary differential equations is such a fundamental problem that library subroutines will have been prepared for it in any case. These will not deal with the problem entirely because the evaluations of the functions which are specific to these particular equations will have to be programmed. Since the function $P(v)$ is of a rather untidy nature demanding a table with a large number of entries to cover the whole range of permissible velocities, the most convenient procedure is to fit a series of polynomials in v which will give $P(v)$ to the accuracy of the table. A number of polynomials, each with a few terms and covering a limited range of v, is more economical than one polynomial covering the whole range. The computation of these polynomials will have to be undertaken afresh each time the empirical function $P(v)$ is changed, but they can be computed on an electronic computer as part of the initial preparation of the main programme. The function $f(y)$ is of a simple nature and merely involves the calculation of an exponential, again a library subroutine. The total labour, therefore, in programming the computation of trajectories is quite reasonable having regard to the extensive use which will be made of the programme when it is complete, and in fact it may be classified as one of the most satisfactory computations.

As a second example we may consider the "traverse" calculations which arise in survey work. The central computation involved is quite simple. Suppose we are given a path $ABCD$ (Fig. 1) . . . consisting of a number of straight lines, and the distances AB, BC, CD, . . . denoted by r_1, r_2, r_3, . . . are given and the angles A_1, A_2, A_3 . . . , made by these lines with a fixed direction. Then the Cartesian co-ordinates of the point D are given by

$$r_1 \cos A_1 + r_2 \cos A_2 + r_3 \cos A_3$$
and
$$r_1 \sin A_1 + r_2 \sin A_2 + r_3 \sin A_3$$

Given a sequence of distances and angles the programme for calculating these co-ordinates is trivial, particularly as there will be standard subroutines for $\cos A$ and $\sin A$. If a second path AB_1, B_1C_1, C_1D is given, with distances r_1', r_2' and r_3' and angles A_1', A_2' and A_3' the co-ordinates of D are also given by

$$r_1' \cos A_1' + r_2' \cos A_2' + r_3' \cos A_3'$$
$$r_1' \sin A_1' + r_2' \sin A_2' + r_3' \sin A_3'$$

Now in survey work the values for these distances and angles are derived from field observations, and the work is of such a nature that the percentage of errors in the data is far from negligible. A test for the accuracy of observations is the agreement, within the tolerances permitted, of the co-ordinates of D obtained from the two sets of observations. In spite of the apparent simplicity of the work it does not appear to be suitable for an electronic computer. At present the field records are made on paper and the data would have to be punched up before a machine could be used. This objection could be removed by recording the data on cards right from the start, but it is likely that the speed of the electronic machine would still be wasted due to the number of traverses which would have to be referred back as a result of unsatisfactory checks. In view of the importance of the work, and the very large number of computations required every year, it is too early to say that a satisfactory method of applying an electronic computer will not be found, but it is hardly likely to give the ratio of effectiveness compared with desk machines which is achieved on the computation of trajectories.

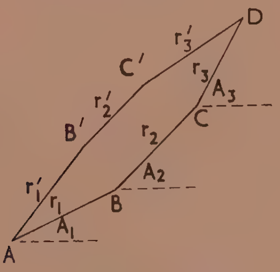


Fig. 1. A simple traverse network

An interesting example of the use of high-speed computers arises in the aircraft industry in determination of the critical velocities of an aircraft with respect to flutter. The problem, generalized a little to include problems of a similar nature, may be expressed mathematically, as follows. We are given a set of second order differential equations in n unknowns in which the coefficients of the derivatives are constants which are functions of a parameter V. These may be represented by

$$A\ddot{x} + B\dot{x} + Cx = 0$$

where A, B and C are (nxn) matrices which are functions of V, and x is a vector with n components. The general theory of such equations shows that each of the n dependent variables may be expressed as the sum of multiples of n exponentials $\exp(\lambda_1 t)$, $\exp(\lambda_2 t)$, . . . $\exp(\lambda_n t)$ where the λ_i are, in general, complex. Now if the real parts of all the λ_i are negative the solutions tend to zero as t tends to infinity, but if any of the λ_i is positive the solutions increase indefinitely with t. The values of λ_i are functions of V and a critical value V_i is one for which one of the λ_i has zero real part. For values less than V_i it will have a negative real part and for higher values a positive real part. This problem is usually solved on an analogue machine, known as a flutter simulator which was designed specifically for the work. Using this machine
coefficients in the equations are set up manually and then
behaviour of the solution can be watched visually while
varied by turning a knob. The simulator is a very satisfact
machine in most instances, but sometimes there are diffi
cases which it cannot resolve. Moreover the number
equations which a simulator can treat is strictly limited.
simulator to deal with six equations, for instance, is a v
expensive piece of equipment. The problem has now b
solved satisfactorily by digital methods and the most rec
programme on the Pilot ACE takes about three minutes
find the values of λ_i corresponding to one value of V. T
gives the λ_i to a high degree of accuracy. The programm
not limited in its range of application and has already b
used to deal with nine simultaneous equations. It has b
very successful on those cases which gave difficulty on
flutter simulators. In this example the main difficulty
not that of programming the computation, but of develop
a numerical technique which would give the required accur
in a reasonable time. Although considerable effort has b
expended in order to produce a satisfactory solution,
effort has been fully justified for two reasons. In the f
place the problem is of sufficient importance for it to ha
been worthwhile in the past to build more than one expens
analogue machine to deal with it. The completed program
is of value in other fields of work since equations of
above type are of common occurrence.

As a final example we may consider the use of an electro
computer in lens design. In order to examine the perfor
ance of a system of lens by theoretical means, the fundamen
computation involved is the determination of the path o
ray of light through that system. To simplify the presentat
it is assumed that all the surfaces involved are spherical
plane and that the ray is not skew, though there is no reas
why non-spherical surfaces should not be treated in a reas
ably simple manner and a programme already exists
more than one machine for calculating the paths of sk
rays through spherical and plane surfaces. Fig. 2 shows t
successive surfaces of the system and a ray $P'PQ$. The o
physical principle involved is Snell's law at each of
surfaces. The parameters used to specify a surface are
distance d from the previous surface, the curvature ρ of
surface, which is equal to the reciprocal of the radius an

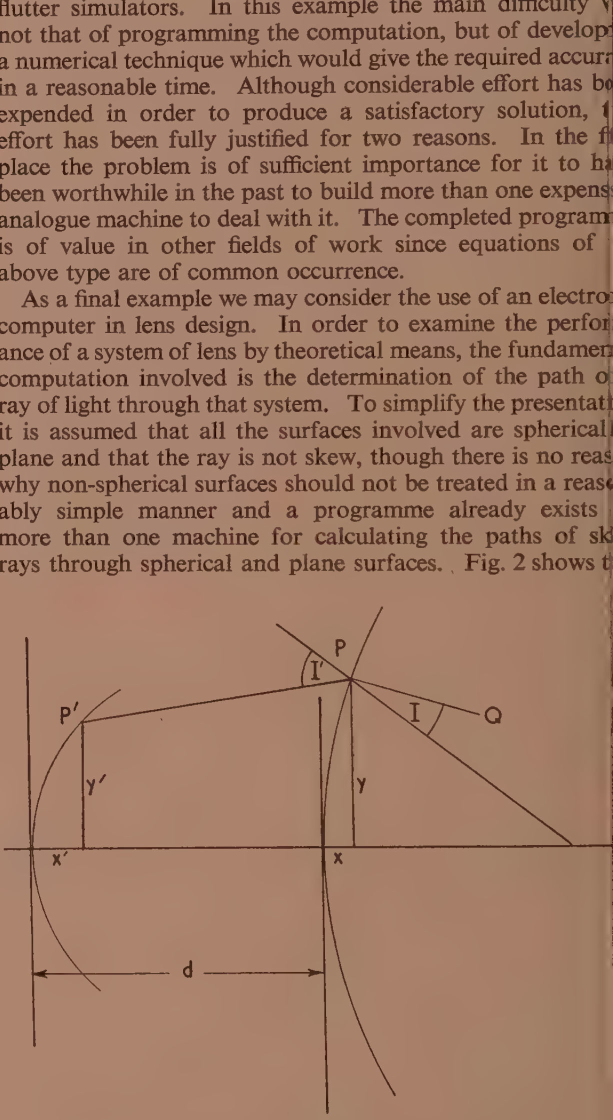


Fig. 2. Refraction of light ray at spherical surface

refore zero for a plane surface, and the ratio μ'/μ of the ractive index of the two media at which refraction is taking ce. Co-ordinates are taken at each surface with respect the point of intersection of that surface with the axis of nmetry. In general, dashed characters refer to the previous face and undashed to the current surface. The direction sines of the ray $P'P$ are l' and m' and of the ray PQ are nd m.

Snell's law gives $\mu \sin I = \mu' \sin I'$ where I and I' are the gles made with the normal to the surface. x, y, l and m then determined from x', y', l' and m' merely by the ometry of the system. There are many different ways in ich the details of the calculation may be formulated, but following steps have been found convenient on an ctronic computer. They have been formulated so as to ep the number of arithmetic operations as low as possible d also so that for plane surfaces, for which $\rho = 0$, they do t lead to indeterminate expressions, as do some methods formulation which might otherwise appear more natural. e quantities defined below are calculated in the order given

$$
\begin{aligned}
A &= l' - \rho[l'(x' - d) + m'y'] \\
B &= \rho[(x' - d)^2 + (y')^2] - 2(x' - d) \\
C &= \sin^2 I' = 1 - A^2 + \rho B \\
D &= \cos I' = \sqrt{(1 - C)} \\
H &= \cos I = \sqrt{[1 - (\mu'/\mu)^2 C]} \\
E &= H - (\mu'/\mu)D \\
F &= B/(A + D) \\
x &= Fl' + x' - d \\
y &= Fm' + y' \\
l &= (\mu'/\mu)l' - (\rho E)x + E \\
m &= (\mu'/\mu)m' - (\rho E)y
\end{aligned}
$$

pressed in this form, the calculation at each surface requires o square roots, one division and eighteen multiplications. the Pilot ACE the computation takes of the order of one-h of a second per ray per surface. It is interesting that ew rays, which are normally regarded as much more rmidable, may be dealt with by a process that takes only more multiplications per ray per surface. The basic sub-utine is one which, when provided with data specifying the mber of surfaces, their curvatures, the distances between surfaces and their refractive indices will trace any ray rough the whole set of surfaces, given the initial co-dinates of that ray. The subroutine may be used in many ferent ways. The designer may wish to examine the rformance of a promising lens system by computing the ths of a number of specified rays, not only through the oposed system but also through a number of other systems, ch of which differs slightly from it. He will then be able examine the effect of small variations in design and, for ample, choose a combination of these variations which will nimize some aberration. To do this he could provide the sic programme with a number of different sets of data ecifying the various lens systems, but it is more satisfactory devise an extra programme which will produce the different s of parameters internally, given the basic values. Alterna-ely, a programme may be devised which will itself determine variations which will minimize the required aberration. Experience has shown that at present there are wide variations in the current practice and requirements of lens designers which leads to a corresponding multiplicity of programmes, and to meet all their requirements would need quite a considerable programming effort. At present, while lens designers are mainly content to use the services of a programmer who is working on a computer which is being used for general purposes, this is an unsatisfactory situation because it is unlikely that such a programmer will be able to devote more than a modest proportion of his time to programmes in this field. In these circumstances a rationalization of requirements would certainly pay handsome dividends. If, however, the optical industry found it worth its while to purchase a computer there is no reason why one or two programmers should not produce all the programmes that are needed at the moment, though first-hand experience of the machine would probably suggest many more uses for it.

Such a rationalization of its requirements has already been successfully undertaken by the British aircraft industry which has formed a special panel, the work of which is to devise a number of standard forms in which problems from the various firms should be framed whenever possible. The aircraft industry makes far greater use of electronic computers at present than all other industrial users combined and several firms have placed orders for electronic computers for their own use. The probable reason for this is that the aircraft industry had already made extensive use of numerical methods before the advent of electronic computers and was therefore better prepared to take advantage of the new equipment. The same remark also applies to the Defence Ministries and up to the present a very high percentage of all scientific computation has been done for them. During the first five years of operation of the new machines while there has been only a few in existence, the demand for machine time from those who were already converted to using them has been so great that there has been little incentive to encourage their use in fields where the demand was not ready made. In the next two years so many more machines will be produced that we can expect to see the field of application covering a much wider range of physics and engineering.

REFERENCES

(1) Hartree, D. R. *Calculating Instruments and Machines* (Urbana: The University of Illinois Press, 1949).

(2) Williams, F. C., Filburn, T., and Toothill, G. C. *Proc. Instn Elect. Engrs*, **98**, p. 13 (1951).

(3) Wilkes, M. V., and Renwick, W. *J. Sci. Instrum.*, **26**, p. 385 (1949).

(4) Wilkinson, J. H. *The Pilot ACE. Automatic Digital Computation. Proceedings of a Symposium held at N.P.L.* (London: Her Majesty's Stationery Office, 1954).

(5) *The Scope for Electronic Computers in the Office* (London: Office Management Association, 1955).

(6) Wilkes, M. V., Wheeler, D. J., and Gill, S. *The Preparation of Programmes for an Electronic Digital Computer* (Cambridge, Mass.: Addison-Wesley Press Inc., 1951).

ORIGINAL CONTRIBUTIONS

A platinum resistance thermometer for use at low temperatures

By C. R. Barber, B.Sc., F.Inst.P., National Physical Laboratory, Teddington, Middlesex

[*Paper received* 15 *July*, 1955]

A platinum resistance thermometer of external dimensions 75 × 2·5 mm suitable for use at low temperatures is described. The resistance coil is sealed in a thin-walled platinum sheath in an atmosphere of helium by means of a lead glass to platinum seal. The reproducibility of reading is shown to be ±0·001° C at the ice point after a number of temperature cycles down to − 260° C over a period of 16 months.

A uniform temperature region for investigations below −183° C is often achieved by thermally isolating a copper block or container in an enclosure cooled with liquid hydrogen or helium. For temperatures down to about −260° C it is possible to measure the temperature by means of a platinum resistance thermometer which has been calibrated by comparison with a gas thermometer.* The conventional platinum resistance thermometer with a long glass sheath is not generally suitable for this purpose since the conduction of heat into the block is prohibitive. Thermal contact with the copper block can be improved by containing the thermometer coil in an atmosphere of helium in a thin platinum sheath which is a good sliding fit into holes in the block or to which it may be soldered. Short platinum leads are sealed through a lead–glass cap closing the top of the platinum sheath and very fine copper leads are joined to the platinum and carried out of the enclosure to the measuring apparatus. Thermometers of this type, 50 mm in length and 5·6 mm in diameter, are made commercially in the U.S.A.

The use of very fine connecting leads to the thermometer results in a high ratio of lead to bulb resistance when the bulb is at a very low temperature. In consequence the Smith bridge method of resistance measurement normally employed at N.P.L. for resistance thermometry is not very suitable for such a thermometer. A potentiometer method is therefore used in which changes of lead resistance have no effect upon the accuracy of measurement except in so far as the sensitivity is affected and it is not necessary, as with the bridge method, to adjust the leads to be closely equal in resistance. Standard resistance thermometers used for temperatures above the boiling point of oxygen are commonly of 25 Ω resistance at the ice point. It is possible to read the resistance of suc thermometer at the boiling point of hydrogen with a precis equivalent to 0·001° C, represented by about 1 in 10^4 i resistance of 0·1 Ω, corresponding to 0·05 μV in e.m.f. w the measuring current is 5 mA.

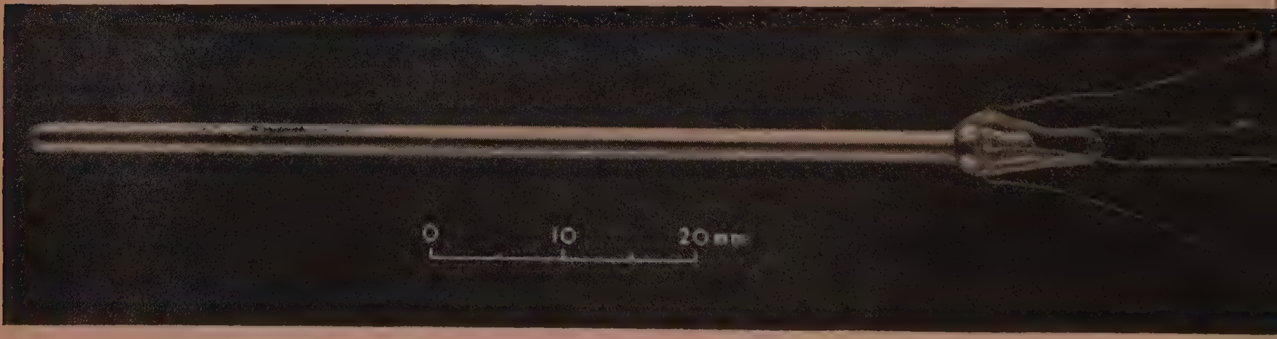


Fig. 1. Platinum-sheathed resistance thermometer

The requirements of the thermometer to fulfil our purp were as follows: resistance at the ice point to be 25 Ω, ove length of the bulb coil to be 60–65 mm, external diamete sheath to be as small as possible, reproducibility of read to be 0·001° C. The design of bulb adopted to satisfy th conditions is illustrated in Figs. 1 and 2 and the follow method of construction was employed. About 120 cm pure platinum wire, 0·075 mm in diameter, was wound o silver-steel rod 1 mm diameter, with a uniform spacing about 50 turns/cm. Alternatively the coil can be wound the rod with turns touching and then drawn out to required length. Provided the tension is constant dur winding, a uniform spacing of turns can be obtained in t way. Two 0·1 mm platinum wires were threaded throug twin-bore silica tube of diameter 1 mm and fused togethe one end, the junction projecting from the sheath by so 4 mm. This junction was then bent back sharply to lie the silica tube and a steatite ring (2·3 mm diamet previously fired to 1000° C, was slipped over the tube a wires to hold them in position. The platinum coil v threaded on to the silica tube and one end of it fused to junction of the two leads already in position. The two le for the other end of the coil were now fused together a held on to the silica tube by another steatite ring and end of the coil fused to these leads. The two rings of stea were fixed in position by a small amount of refractory cem (pure alumina and sodium silicate). At the lower end cement covered the bend in the leads to prevent electri contact with the sheath. The coil thus assembled was pla

---

* Hoge, H. J., and Brickwedde, F. G. *J. Res. Nat. Bur. Stand.*, 22 p. 351 (1939).

Stability of thermometers

hermometer No.	R_{ICE} (Ω) *November 1953*	R_{ICE} (Ω) *March 1955*	*Change in R_{ICE} (°C equivalent)*	α × 10^3 *November 1953*	α × 10^3 *March 1955*	*Change in α (°C equivalent on F.I.*
1	$22\cdot7239_7$	$22\cdot7241_0$	$+0\cdot001_3$	$3\cdot9234_9$	$3\cdot9234_3$	$-0\cdot001_5$
2	$23\cdot1091_2$	$23\cdot1092_1$	$+0\cdot001_0$	$3\cdot9171_9$	$3\cdot9172_8$	$+0\cdot002_2$
3	$23\cdot4589_7$	$23\cdot4591_0$	$+0\cdot001_4$	$3\cdot9214_2$	$3\cdot9214_5$	$+0\cdot000_7$
4	$23\cdot6372_1$	$23\cdot6374_6$	$+0\cdot002_6$	$3\cdot9242_5$	$3\cdot9241_7$	$-0\cdot002_0$
5	$23\cdot7880_4$	$23\cdot7883_8$	$+0\cdot003_6$	$3\cdot9196_5$	$3\cdot9196_2$	$-0\cdot000_7$
		mean	$+0\cdot002_0$		mean	$-0\cdot000_3$

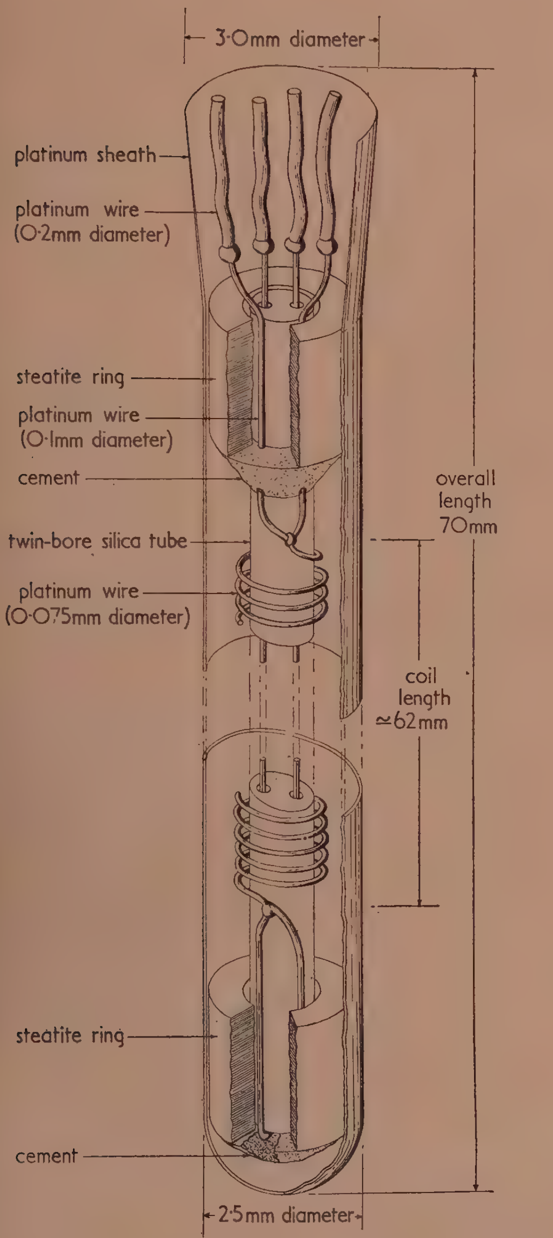


Fig. 2. Internal construction of platinum-sheathed resistance thermometer

in a clean silica tube and annealed in a horizontal position in air in a furnace at 800° C for 16 h. The platinum sheath was 0·09 in. in internal diameter and 0·10 in. in external diameter (2·29 and 2·54 mm respectively) and was closed at one end. The open end was spun out to a diameter of 3 mm and the edge was "feathered." A small amount of lead glass was fused on to this edge so that the latter was embedded in the glass. The coil was lowered into the sheath with great care since the wire was extremely soft after annealing and could easily be deformed. The coil was held coaxially in the tube by the steatite rings which were made to be an easy sliding fit in the platinum sheath. These rings thus serve the purpose of providing an annular space in which the coil is free to move without touching the wall of the platinum sheath, and of anchoring the leads. The four leads were bent over the glass-covered edge of the sheath and a bell-mouthed tube of lead glass with a constriction close to the end was fused on, at the same time sealing in the leads. The thermometer was evacuated at 350° C to dry it and filled with helium at a pressure of 25 cm of mercury. It is important to ensure that all parts of the thermometer are clean, and they were therefore washed in benzene and then boiled in dilute nitric acid followed by several washings in distilled water. After assembly, and just before the annealing treatment, the coil assembly was washed in benzene.

Ten thermometers of this type were constructed in November 1953 from platinum wires from different sources for purposes of temperature scale investigations. Five of these have been in use from time to time at temperatures down to −260° C. The table shows the values of the resistances of the thermometers at the ice point and the resistance-temperature coefficients for the 0–100° C interval (α) as recorded in November 1953 and in March 1955. The ice-point resistance of each thermometer has risen slightly, the mean rise being equivalent to 0·002° C. The mean change in α is equivalent to −0·0003° C on the fundamental interval (F.I.). Since these changes took place after several excursions of temperature down to −260° C spread over a period of 16 months, the thermometers are evidently sufficiently stable for the precision of measurement required.

ACKNOWLEDGEMENTS

The work described in this paper was carried out as part of the research programme of the National Physical Laboratory and it is published by permission of the Director of the Laboratory. The author wishes to acknowledge the assistance given by Mr. H. Conway in constructing the coils and to Miss A. Horsford in making resistance measurements.

An integrating photometer employing scalloped gratings

By L. R. Baker, A.R.C.S., B.Sc.,* Imperial College of Science and Technology, London, S.W.7

[*Paper first received* 1 *April, and in final form* 22 *July*, 1955]

A new type of controlled-diffuser consisting of a scalloped grating has been developed, and this leads to the design of a high accuracy integrating photometer, which can operate when the total light flux is below one microlumen. Both the theory and the details of preparation of a scalloped grating diffuser are given. An experiment illustrating the efficiency of the scalloped grating relative to other diffusers is described together with an experimental test on a particular design of integrating photometer.

An integrating photometer was recently needed for measuring the mean light transmission of a filter. The requirements of the apparatus were that it should be accurate to within 1% even when the total flux output was below one microlumen, and also that it should be suitable for testing special filters having a non-uniform transmission across their area.

A two-beam flicker photometer(1) was employed, the essential parts of which are shown schematically in Fig. 1. A slit source S is conjugate to the roof mirror R with the light passing through a polarization system P_1, W, P_2 similar to that used in the Hardy spectrophotometer.(2) The Wollaston prism W causes the formation of two slit images at R which are separated by a small distance and polarized at right angles. The Polaroid P_2 is continuously rotating so as to present the light alternatively to the test beam T containing the filter F and the comparison beam C. The ratio of intensity in these beams can be controlled by the angular setting of the first Polaroid P_1. Field lenses F_1 and F_2 image the exit pupil of the previous lens at the entrance pupils of the collimating lenses C_1 and C_2. The two parallel beams produced by these lenses are eventually recombined at the semi-reflecting diagonal E and focused by L into the plane of the aperture M. A diffusing element G serves to produce an essentially uniform patch of light at M which can then be viewed with an eyepiece. If ϕ_0 and ϕ are the angular settings of P_1 giving no flicker at M before and after F is in position, then its mean transmission is given by $\tan^2\phi/\tan^2\phi_0$.

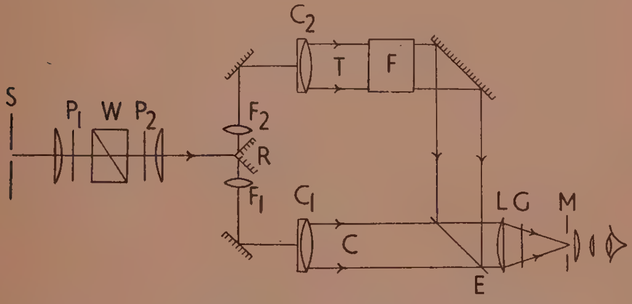


Fig. 1. An integrating photometer employing a scalloped grating G

The ultimate precision with which a setting can be made will depend on the brightness discrimination of the detector, and a practical limit to this will be set by the total amount of light available. If either the light transmission of F is very low, or the width of S is very small so as, for example, to ensure partial coherence across the width of each beam, the total light flux may be as low as one microlumen. It will be seen, moreover, that an additional loss of light takes place at G. The mode of action of this diffuser, which be a piece of opal glass or an integrating sphere, is to sca the incident light in all directions so that, in practice, about 10% eventually reaches the detector. The possib of constructing a controlled-diffuser has been considered which perfect integration still takes place whilst at the s time preserving the directional properties of the rays.

THE PRINCIPLE OF THE CONTROLLED-DIFFUS

In Fig. 1 the square aperture M contains an image of original source slit S, and its height equals the length of image. The purpose of the diffuser is to spread out the image so as to fill M with a uniform patch of light e though F may have a non-uniform transmission. One in which this can be done is by placing a diffraction gra G between L and M. The grating spacing and its posit are chosen so that the entire aperture is filled with the adjac orders.

The type of grating best suited to this purpose is one giv a large number of orders in the diffraction envelope,(3) this requirement leads to the design of an amplitude grat in which the ratio of period to line width is as large as possi Apart from the difficulties of constructing such a grating ruling very narrow lines in a metallic film, one would practice, derive very little advantage from its use because the very low light transmission. A more efficient grat from this point of view, and also much easier to make one composed of either positive(4) or negative lentic elements. In this device the effective grating lines are optic reduced images of the original slit source and in theory only limited in width by the effects of diffraction.

A grating which is easy to prepare and very satisfactory practice is one composed of plano-concave-cylindrical elements. It is made from a transparent material and ha scalloped profile on one side. An enlarged section thro such a grating is shown in Fig. 2. If the medium of grating on the left has a refractive index of 1·5 and radius of the scallops is a, then a parallel incident beam have a virtual diffraction focus distant $2a$ to the left, and limiting rays will diverge with $\theta \simeq \tan^{-1}\frac{1}{3}$. For lar incident heights both vignetting and total internal reflex take place.

The smallest width of the source image at the focus these lens elements will be limited by diffraction,(3) and of the order of $\lambda/\sin\theta \simeq 3\lambda$ which is independent of a. further limitation to the width of this line image will be by the presence of aberrations which will tend to blur diffraction image. In theory these could be made neglig by using a hyperbolic instead of circular profile, but i doubtful if this improvement would be worth while unles could be easily carried out. The reason for this is t owing to the small radius of curvature of the lens c nents, the primary aberrations are generally not more than vavelength.

---

* Now at Royal Aircraft Establishment, Farnborough.

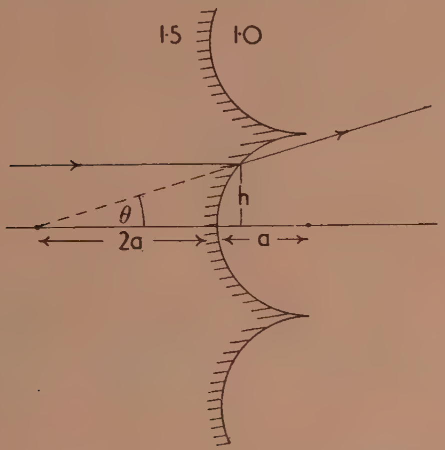


Fig. 2. Enlarged section through a scalloped grating

It is interesting now to compare the relative efficiency of s type of phase grating with its equivalent amplitude ating having the same number of spectra in the principal aximum of the diffraction envelope. The number of orders the envelope is given by the ratio of spacing to ruling idth,(3) and for the scalloped grating this will be $2a/3\lambda$ epending only on a for a given wavelength. The equivalent nplitude grating would have a spacing of $2a$ and a ruling idth of 3λ so that its effective light transmission is therefore $\lambda/2a = 0{\cdot}02$ when say $a = 80\lambda$ compared with $h/a = 0{\cdot}67$ r the scalloped grating.

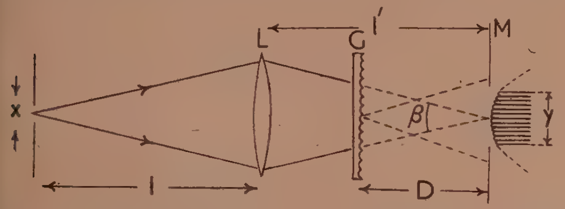


Fig. 3. The grating must be positioned between the lens *L* and mask *M* to ensure adjacent spectra

The various parameters of importance in designing a articular diffusing system may be understood by applying e laws of geometrical optics and the grating formula to e general arrangement shown in Fig. 3. Let the slit source e of width x so that, with conjugates l and l' as shown, its nage is of width xl'/l. If α is the angle of diffraction, then om the grating formula we have

$$\lambda = 2a \sin \alpha \tag{1}$$

nd if the orders are to touch we must have

$$\sin \alpha = \lambda/2a = xl'/lD \tag{2}$$

here D is the separation of the grating and the final image ane and α is the angular separation of the spectra. In e special case of equal conjugates we have the simple rmula

$$2a/\lambda = D/x \tag{3}$$

ving the relationship between the source size and the osition of the grating between L and the mask M. The width of the virtual source image formed by each grating element on the basis of geometrical optics will be $xl'2a/lD$ which, from equation (2), under the conditions of adjacent spectra must be equal to one wavelength. It follows, therefore, that diffraction will predominate and we must assume that these images are at least of width 3λ. The total number of spectra will be twice the number of orders, and so if we mask off half of these so as only to accept those of roughly equal intensity we are left with $2a/3\lambda$ images which, in practice, should not be greater than about 100. If the mask is of width y then for equal conjugates

$$2ax/3\lambda = y \tag{4}$$

There must also be some limitations on D according to the angle of the convergent beam β. Suppose there are n grating periods in this beam so that $2an = D \sin \beta$ and if we divide this by equation (3) we are left with

$$n = x/(\lambda/\sin \beta) \tag{5}$$

The physical meaning of this result is that the number of elements illuminated is equal to the ratio of the source width to the resolving power of the convergent cone. In practice this should be at least ten so that the device cannot be used with images near the resolving power limit (although the aberrations of L are ignored).

By way of example suppose a very narrow slit source is required in order to ensure some degree of coherence across the beam and $x = 0{\cdot}001$ in. Then if we require $y = 0{\cdot}1$ in. it follows from equation (4) that $2a/\lambda = 300$ and the period of the grating will be $0{\cdot}006$ in. The actual position of the grating can be found from equation (3) where we find that $D/x = 300$ and $D = 0{\cdot}3$ in. A similar calculation when $x = 0{\cdot}1$ in. and $y = 1$ in. gives $2a/\lambda = 30$ or a grating period of $0{\cdot}0006$ in. and $D = 3$ in.

The actual shape of the diffraction envelope is given by the Fraunhofer diffraction pattern of each element of the grating.(3) In the author's case the complex amplitude in each element is that obtaining at the diffraction focus of a cylindrical lens, and so, at least in theory, is of the form $\sin x/(x)$.(3) The Fraunhofer diffraction pattern given by such a distribution of complex amplitude is square-topped in form so that the spectra should have constant intensity up to a certain number and zero intensity thereafter. The diffraction envelope obtained with a true amplitude grating will, however, be of the form $\sin x/(x)$ giving a less uniform distribution of intensity in the spectra. Scalloped gratings used in practice have a performance somewhere between these two extremes and require a mask to cut off the low intensity spectra.

The principal uses of lenticular screens appear to have been for office block window glass, for stereoscopic photography,(5) and, possibly, for certain types of television screen. A particularly interesting application is to be found in the production of high resolution moiré patterns. A moiré pattern is formed in a plane conjugate to two gratings, the axes of which are slightly inclined. If the gratings are highly blazed the single order from each produces a sine wave interference pattern. The scalloped gratings, however, have a large number of orders of equal intensity so that, in this case, multiple beam interference takes place, and a moiré pattern of very sharp lines is produced.

PREPARATION OF THE SCALLOPED GRATING

Lenticular gratings composed of plano-convex lenses are available commercially with up to 100 lines per inch and are quite suitable for many purposes. The technique to be described, however, was specially developed for making scalloped gratings with up to 2000 lines per inch. Scalloped gratings can be conveniently made as replicas taken from a wire wound screw.(6) A single layer of wire of diameter equal to the grating spacing required is wound on to a cylindrical metal former so that all the turns are touching and closely wound. The replica technique for producing high-grade flat gratings from a fine screw has already been described,(7) but the following method has been found more convenient in practice since it requires no special chemicals or apparatus and yet gives results sufficiently good for the purpose.

The scalloped profile is formed on the gelatine emulsion of a photographic film by pressing the latter on to the surface of the screw. In order that the gelatine should fill the space between the top halves of the wires it is easily seen that the diameter of the wire should not be more than ten times the thickness of the gelatine layer. Since the layer of gelatine on a piece of film is about 0·001 in. thick in the dry state, the wire should not have a diameter greater than 0·01 in. The actual thickness of wire chosen will be determined by the number of orders required in the diffraction envelope. For wire 0·01 in. in diameter there will be about 100 orders or 200 images visible.

The replica is made by fixing and washing a piece of undeveloped clear based film, which is then soaked for an hour in a weakly dichromated glazing solution, and finally bound round the wire screw with the aid of a piece of tape. The time the film is left in contact with the screw is very important in determining the quality of the grating. If it is left for about half an hour the diffraction grating shows three spectra, indicating that the profile has a corrogated or sine wave form. If, however, the film is allowed to dry on the screw overnight the scalloped surface will be torn and irregular, giving a large amount of scattered light in the image. It has been found that a forming period of between two and three hours at room temperature provides a clear diffraction image, in which a significant proportion of the spectra have roughly the same intensity. When the grating is removed from the screw it is, of course, still damp, and so should be put aside for a few days to dry thoroughly. It may well be that under certain conditions the desirable hyperbolic type of profile could be produced by a slight distortion of the replica on drying down. Experiments have been carried out on removing the gelatine pellicle from a grey celluloid backing so as to achieve a higher transmission, but these were not successful. It was found more convenient to select films with a transparent base.

A COMPARISON BETWEEN THE SCALLOPED GRATING AND OTHER DIFFUSERS

Due to the imperfections of any given scalloped grating all the spectra will not have the same intensity, and so those near the edge of the diffraction envelope are masked off by means of an aperture such as M in Fig. 1. The efficiency of the scalloped grating as compared with other diffusers is therefore uncertain and so it was decided to carry out an experiment of direct comparison.

The distribution of intensity at M was determined photographically by using the technique employed in the wedge spectrograph.(8,9,10) A linear variation of exposure in the vertical direction was obtained by rotating a suitably shaped aperture in front of the photographic plate upon which was an image of M, and by increasing the time of exposure t vertical axis of intensity could be conveniently expanded.

The recorded intensity distribution at M under vario conditions is shown in Fig. 4 where the intensity magnificati factors obtained by an increase in exposure are shown abo each photograph. Part 1(a) of Fig. 4 shows the distributi of intensity in the single slit image formed at M. Part 1 has its vertical axis increased ten times compared w part 1(a) and is the diffraction image produced by placing scalloped grating at G. Part 1(c) shows the effect of movi G towards M so that the spectra close into the aperture Part 1(d) is the distribution of intensity in M when the spect are just touching.

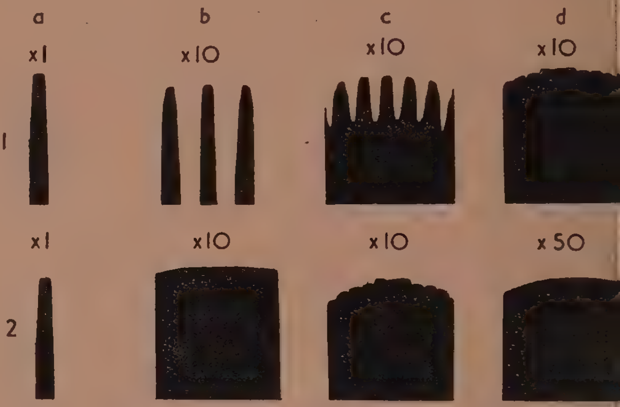


Fig. 4. Wedge spectrograph comparison betwee various diffusers

Line 2 gives a comparison between methods of integrati the slit image to form a square patch of light. Part 2(a) = 1(Part 2(b) is the distribution of intensity obtained by Maxwellian view where a lens replaces the grating at G a images the exit pupil of the previous lens at M. In this case t only light lost is due to a vignetting of the circular pupil by Part 2(c) = 1(d). Part 2(d) shows the maximum intens obtainable by the use of a ground glass diffuser at G. T vertical axis is times fifty in this case.

The scalloped grating used in this experiment had 714 lin to the inch and the diffraction envelope was observed to ha fifteen orders. An amplitude grating producing roughly t same diffraction image would have an effective transmissi of $\frac{1}{15}$ which is about $\frac{1}{9}$ of that obtainable with a scallop grating. It is clear therefore that an amplitude grati would be worse even than a ground glass diffuser. integrating sphere would also be worse than ground glass the emergent light would be spread out over about ten tim the solid angle.

There is every reason to believe that the quality of t scalloped grating as illustrated here can be improved, b even with this one the level of intensity of the diffused pat is comparable with that obtained with the Maxwellian vie and is five times better than the highest intensity obtaina with a ground glass diffuser.

A VISUAL PHOTOMETER EMPLOYING A SCALLOPED GRATING

Although the scalloped grating has a transmission whi is higher than other diffusers it yet remains to be seen wheth its ability to integrate light is as good. If F in Fig. 1 has uniform transmission then a Maxwellian view may be use ut in the author's case this is not so, and it is necessary to ew the plane M conjugate to the source, since this is the aly one containing no direct evidence of the non-uniformity F. With G removed the distribution of intensity at M ill be the Fraunhofer diffraction pattern of the wave coming om F, and will therefore contain indirect evidence of a on-uniformity in F. Provided, however, that the aperture M is large compared with this pattern the distribution of tensity in the diffused image when G is present should be dependent of a non-uniformity in F. If F is a very small perture diffraction effects may become important, but they e insignificant in most cases.

A two-beam visual flicker photometer employing a scalloped rating diffuser was constructed according to the arrangement nown in Fig. 1. In a trial experiment the light flux in beam was varied in a known way by hanging ball bearings of ifferent sizes from a small bar magnet placed with its end st inside the beam. The reduced transmission thereby aused was off-set by a rotation ϕ of the equalizing polarizer. the apparatus was working correctly the intensity $\tan^2 \phi$ hould be a linear function of the square of the radius r of e ball bearing and Fig. 5 shows that this is so even for rge values of r when the beam is very nearly filled. Over range of intensities of 10 : 1 the observed errors were not reater than 2% with a mean field luminance of 1000 cd/m^2 f sodium light.

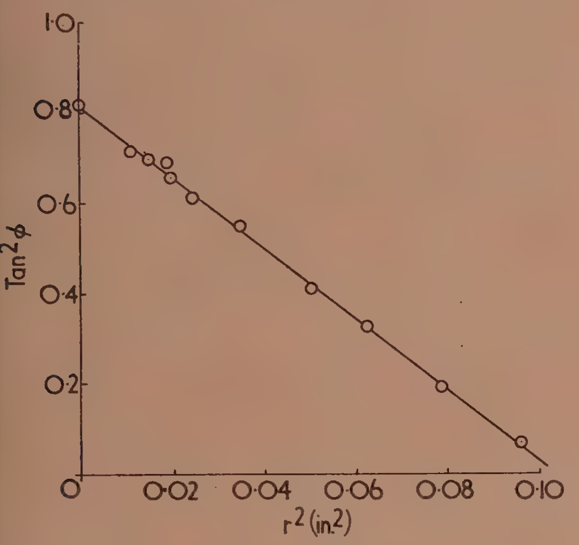


Fig. 5. Showing the efficient integrating properties of the controlled diffuser

This type of integrating photometer has been used successlly for measuring the mean transmission of an interferoetric filter, the aperture of which was partially coherently luminated, and contained a small number of high contrast terference fringes. The total light flux available was below ne microlumen of sodium light giving a field luminance of 50 cd/m^2. The results obtained visually were found to be orrect to about 5%, provided the field luminance did not ll to 10 cd/m^2 when the errors in setting rapidly increased ue to a breakdown of the Weber–Fechner law.$^{(11)}$ It is expected that by the use of a photomultiplier and tuned amplifier circuit instead of the eye the errors will be less than the 1% allowed.

DISCUSSION

Since the transmission and integration properties of the scalloped grating are so good, it seems likely that a simple high accuracy integrating photometer could be constructed. The light flux in the comparison beam could be very accurately controlled by a calibrated slit aperture. In this form the apparatus could be used for measuring irregular areas or estimating the number of particles present in a suspension.

It may be convenient in portable apparatus to have the diffracted images from each beam interlacing instead of superposed, since in this case there would be no need for a motor to produce alternation between the beams. The flux in the comparison beam would be varied until the separate slit images were matched in luminance. Alternatively, a square point source could be used with crossed gratings so as to produce a chequered pattern if the two beams are not balanced.

In the above application the light should be monochromatic, but if the grating is to be used just as a diffuser this is not essential, provided that either the slit images are so fine as not to be resolved by the eye or they are sufficiently extended so as to produce considerable overlapping. Under either of these conditions a grating of 100 lines per inch giving 200 spectra of monochromatic light can produce an effectively uniform patch of white light from a tungsten source.

ACKNOWLEDGEMENTS

Thanks are due to Dr. H. H. Hopkins for helpful discussion on the theory of the scalloped grating, and to the Department of Scientific and Industrial Research for the provision of a maintenance grant.

REFERENCES

(1) Baker, L. R. U.K. Patent Appl. No. 4535/55.

(2) Hardy, A. C. *J. Opt. Soc. Amer.*, **25**, p. 305 (1935).

(3) Jenkins, F. A., and White, H. E. *Fundamentals of Optics* (London: McGraw-Hill Publishing Co. Ltd., 1951).

(4) Hess, W. U.K. Patent No. 13034 (1911).

(5) Dudley, L. P. *Stereoptics* (London: MacDonald and Co. Ltd., 1951).

(6) Baker, L. R. *J. Sci. Instrum.*, **32**, p. 446 (1955).

(7) Dew, G. D., and Sayce, L. A. *Proc. Roy. Soc.*, **207**, p. 278 (1951).

(8) Sawyer, R. A. *Experimental Spectroscopy* (London: Chapman and Hall Ltd., 1951).

(9) Jones, L. A. *J. Opt. Soc. Amer.*, **10**, p. 561 (1925).

(10) Jones, L. A., and Wolf, R. N. *J. Opt. Soc. Amer.*, **35**, p. 559 (1945).

(11) Walsh, W. T. *Photometry* (London: Constable and Co. Ltd., 1949).

Integrating meters for comparing light intensities in plant growth studies

By A. H. Allan, B.E., A.M.I.E.E., and K. J. McCree, M.Sc.,* Dominion Physical Laboratory, Department of Scientific and Industrial Research, New Zealand

[*Paper first received* 22 *March, and in final form* 29 *June*, 1955]

The considerations, so far as they are at present known, which control the design of a light meter for finding the relative amount of visible radiation reaching undergrowth are discussed, and two instruments designed to meet the requirements are described.

The two instruments to be described were designed for studies of plant growth. They were to be used in places where one type of plant grows underneath another, as, for example, clover growing close to the ground under relatively long grasses, or seedlings and undergrowth in the forest. They were to measure the proportion of the light incident on the top cover which reached a horizontal surface in the undergrowth.

Two photocells are connected by cables to a box. One of the cells is put above and the other below the medium, the transmission of which is to be measured. In the box is the recording apparatus, which may be of several kinds. If it is possible to take readings many times a day, an indicating meter may be used, and the design of the apparatus is then very simple. For the present apparatus, observations were to be made only at intervals of days. The recording apparatus was therefore arranged to integrate the light received and show the result on a telephone register. The two channels, one from each photocell, are quite separate, and give separate indications, from which the ratio is obtained by division.

SPECTRAL SENSITIVITY

A major problem in the design of a light meter is that of choosing the correct spectral sensitivity. If the meter were to be used in the field of illumination engineering, its spectral sensitivity would be adjusted to match that of the International Average Eye, as defined by the C.I.E. It would then measure the light in illumination units, such as the lumen per square foot (foot-candle). For plant growth studies, illumination units have no relevance whatever. This may be seen from Fig. 1, where the International Average Eye curve (*A*) is compared with one of the classical plant sensitivity curves, that of Hoover,⁽¹⁾ for wheat (*B*). If an instrument having the sensitivity of curve *A* were used, when the sensitivity the plant were that of curve *B*, it is obvious that variatic of light at a wavelength of 0·44 μ, although important the plant, would barely be recorded by the instrument.

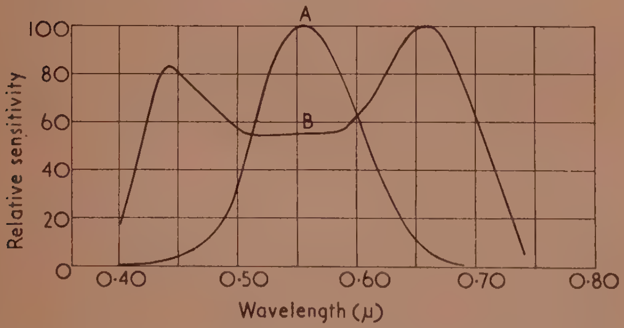


Fig. 1. Spectral sensitivities of human eye (curve *A*) and green plant (curve *B*)

The question arises whether or not the spectral sensitivit of green plants are sufficiently well known, and sufficien similar from one plant to another, to allow the use of c internationally-agreed curve and a special light unit for pla growth studies. At present, the evidence seems to be agai such a solution.⁽²⁾ An alternative suggestion, that t radiation intensity be measured in each of eight bar throughout the entire spectrum [three bands only being the visible region, namely, 0·40–0·51, 0·51–0·61 a 0·61–0·72 μ⁽³⁾], would require a rather complex instrume a spectrophotometer rather than a light meter. The Int national Meteorological Organization⁽⁴⁾ suggests three ban namely, 0·29–0·32, 0·4–0·5 and 0·6–0·7 μ.

In the circumstances, it would seem that the choice sensitivity must be a rather arbitrary one. A free choice more especially possible for the present type of instrume since it is designed for ratio measurements only, and f daylight, which is of relatively constant spectral ener distribution.⁽⁵⁾ Were artificial light to be measured, the is no doubt that spectral energy measurements would al be needed.⁽⁶⁾

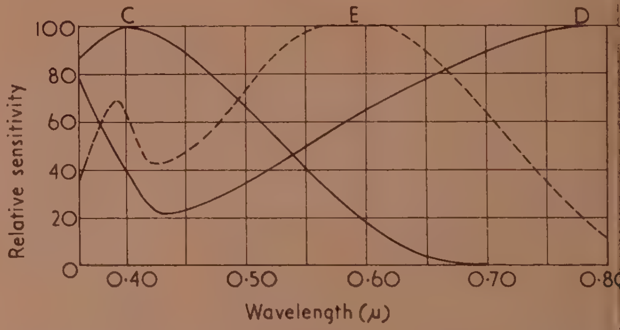


Fig. 2. Spectral sensitivities of caesium–antimony (curve *C*) and caesium–oxygen–silver (curve *D*) photocells, and of curve *D* with 3 mm of Chance ON 13 glass (curve *E*)

In practice, the choice of spectral sensitivity is limited the range of photocells and filters which is readily availab Photoemissive cells were chosen for the present instrume since the photocurrents must be amplified. Of the possib photosensitive surfaces, the two commonest have t characteristics shown in Fig. 2. Caesium-antimony (curve has a peak in the violet region, and the sensitivity to red lig is low. Caesium–oxygen–silver (curve *D*) has two peal one in the near infra-red region at about 0·8 μ, and the oth in the near ultra-violet region at about 0·37 μ, and it ensitive to visible radiation of all wavelengths. It is to be referred for this work.

---

* Now at Imperial College of Science and Technology, London, S.W.7.

The response of an emission photocell with a caesium–xygen–silver surface could be adjusted at will by using a rge number of filters. It is sufficient for this work that the ensitivity be restricted to the visible region, and a suitable lass for this purpose is Chance ON 13. The sensitivity which ould be expected, from the figures in the makers' catalogues, o result from the use of a 3 mm piece of this glass over a hotocell with a caesium–oxygen–silver photocathode, is hown as curve *E* of Fig. 2. The response of the cell to aylight is reduced about four times by this filter. This ombination seems to form the most suitable simple receiver or simulating a plant the spectral sensitivity of which is not nown.

The two photocells for the present instrument were selected o have similar spectral sensitivities (Fig. 3) in order that the tio of the responses would be substantially independent of e spectral quality of the radiation being measured. It is ell known(7) that there are considerable variations among dividual cells and among cells from different makers.

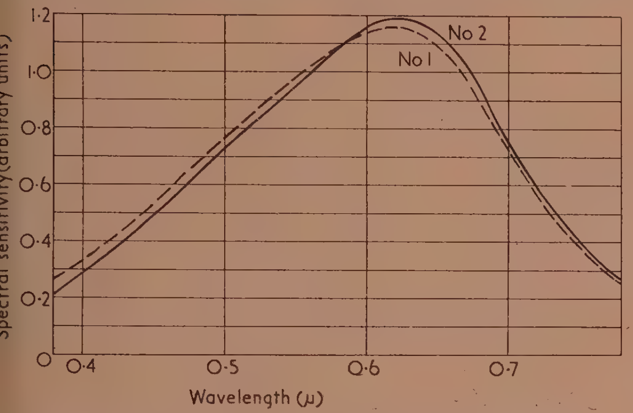


Fig. 3. Spectral sensitivities of the photocell units used in the instrument

ANGULAR SENSITIVITY

There is also some doubt about the proper angular ensitivity for an instrument designed for plant growth udies. A plant may resemble a surface of almost any hape or orientation. In practice, the sensitivity of the strument is restricted to one of two types, the "spherical rface" (omnidirectional) and the "flat surface."(8) They e achieved by covering the photocell with a spherical or a at piece of diffusing material.(9) A "spherical surface" strument might simulate, for example, a single blade of ass, and a "flat surface" instrument a closely-cropped asture.

The "flat surface" type of sensitivity was chosen for this strument. The accuracy with which it approaches the eal, a sensitivity truly proportional to the cosine of the cident angle, is shown in Fig. 4. Of the various diffusing aterials tried, pot opal glass with a rough ground surface ve the best results. There is some excess sensitivity, creasing to 5%, at angles up to 60°, and a large deficiency angles greater than 80°. The practical significance of ese errors cannot easily be estimated, since the angular stribution of the light in the various types of plant growth unknown.

CONSTRUCTION

The cells are connected to two identical integrating electronic amplifiers and digital counters. These count at a rate proportional to the intensity of the radiation falling on the appropriate photocell; in other words, the change in readings of the counters over a given period of time is proportional to the total quantity of radiation which has fallen on the photocell in that time. With this method of measurement it is possible to average-out variations in the radiation intensity.

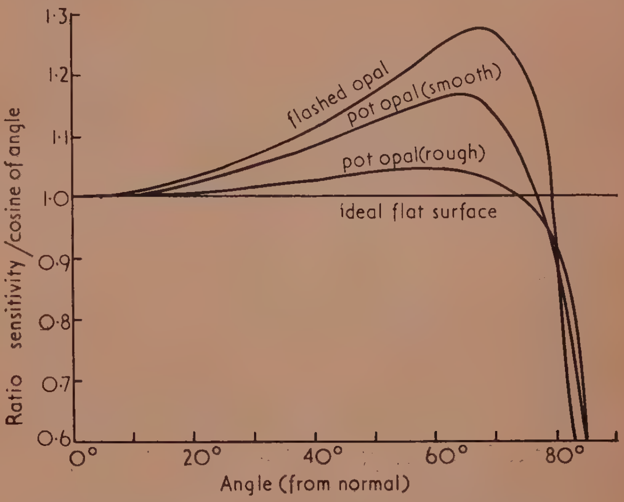


Fig. 4. Comparison of the angular sensitivity of the photocell head, using various diffusers, with that of an ideal "flat" surface

Each photocell is mounted (Fig. 5) in a brass cylinder about 1 in. in diameter, behind the window of opal glass and the spectral correction filter. These reduce the light received by the cells to a safe value, i.e. less than 10 μA cathode current. Flexible polythene-insulated coaxial cables of varying lengths up to 30 ft connect the photocells to the integrating amplifiers.

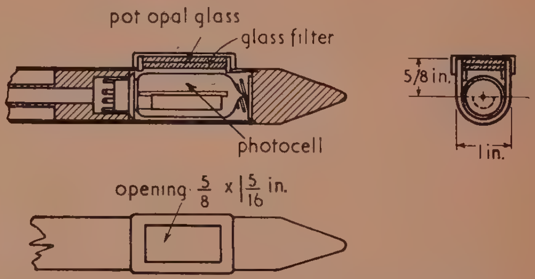


Fig. 5. Construction of photocell head

CIRCUIT

Referring to Fig. 6, the current from the photocell V_1 charges the capacitor C_1, until it reaches a voltage approaching 100 V. At this point the valve V_2, which is connected as a cathode follower, has a cathode voltage approaching that of C_1, and this allows V_3 to conduct. V_3 is normally biased to cut-off by the reference voltage stabilized at +100 V applied to its cathode by V_5. When V_3 conducts, the relay

*A*2 closes and earths the capacitor C_1, through its contacts *A*/1. Simultaneously the other contacts *A*/2 close and actuate the message register. This completes the cycle and C_1 recommences to charge. C_2 provides a short hold-in period for the relay *A*2 to ensure that C_1 is completely discharged.

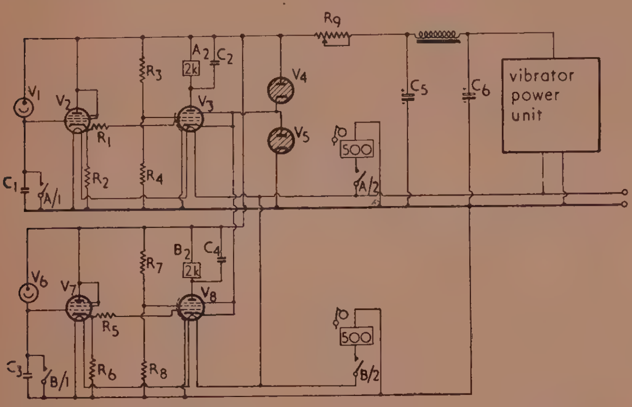


Fig. 6. Circuit diagram of comparison light integrator (twin channel)

C_1–C_4 = 0·25 μF
C_5, C_6 = 16 μF

R_1, R_2 = 100 kΩ
R_3 = 10 kΩ
R_4 = 25 kΩ
R_5, R_6 = 100 kΩ
R_7 = 10 kΩ
R_8 = 25 kΩ
R_9 = 5 kΩ variable

V_1 = 90AV
V_2 = 6J7
V_3 = 6AC7
V_4 = VR150
V_5 = VR105
V_6 = 90AV
V_7 = 6J7
V_8 = 6AC7

Care was taken in the choice of C_1 to ensure that it was of good quality with a small dielectric hysteresis. The leads to C_1 and the contacts *A*/1 are well insulated with polythene.

DIFFERENCES BETWEEN THE TWO INSTRUMENTS

The instrument shown in Fig. 6 is the earlier. It is heavy, and it uses a 12 V accumulator with a vibrator high tension supply which is stabilized by voltage regulator tubes. Because the importance of the spectral characteristic had not been worked out when the instrument was developed, and because the number of types of photocell that were available loca was very limited, caesium-antimony cells were used. Th will not be used for any future instrument. The instrum shown in Fig. 7 was designed to be light and self-contain It operates from two 45 V and four $1\frac{1}{2}$ V dry batteries c tained in a compartment hinged to the bottom of the ampli case, and weighs approximately 20 lb.

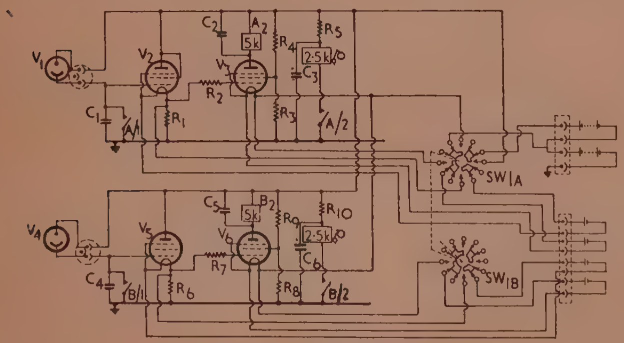


Fig. 7. Circuit diagram of portable comparison light integrator (twin channel)

C_1, C_2 = 0·25 μF
C_3 = 32 μF
C_4, C_5 = 0·25 μF
C_6 = 32 μF

R_1, R_2 = 120 kΩ
R_3 = 22 kΩ
R_4 = 12 kΩ
R_5 = 1 kΩ
R_6, R_7 = 120 kΩ

R_8 = 22 kΩ
R_9 = 12 kΩ
R_{10} = 1 kΩ

V_1 = 90CV
V_2 = 1T4
V_3 = 1S4
V_4 = 90CV
V_5 = 1T4
V_6 = 1S4

FATIGUE

The sensitivities of the photocells of the instrument decre slowly for about half an hour after switching on. Fatigue greater at some light levels than at others, and it may w prove to be unimportant in practice, especially as the ra of the readings from the two heads is generally being measur Nevertheless some measurements in daylight have indica that the fatigue rates of the two heads are not quite equal.

ACCURACY

The counting rates of the two units are not strictly p portional to the intensity of the light incident on the surfa of the heads. Extensive tests have indicated that sm leakage currents are the chief cause of this non-linearity. is greatest at low light levels; if the counting rate is grea than one per minute, the readings of either unit are not lik to be in error by more than 10%, compared with the readir at the highest light levels. The accuracy of integrati depends on the linearity of the current *versus* illuminati relationship of the photocell, and the independence of anode current to anode voltage at constant illumination o the working range.

The accuracy of measurement of light depends, too, the reference voltage of the integrating circuit, but this w affect both cells and the measurement of the ratio of lig intensities will be little affected. The first instrument, havi a stabilized reference voltage, can be calibrated in terms the received light flux. The sensitivity of the portable inst ment must be expected to vary as the battery voltages fall.

The effect of heat on the sensitivity of the photocell he has proved negligible, within the temperature range to 40° C.

REFERENCES

(1) Hoover, W. H. *Smithsonian Misc. Coll.*, **95,** No. (1937).

(2) Rabinowitch, E. I. *Photosynthesis and Related Process* Vol. 1, Part 1, Chapter 30 (New York: Interscier Publishers, Inc., 1951).

(3) Committee on Plant Irradiation, Nederlandse Stichti Voor Verlichtingskunde. *J. Hort. Sci.*, **28,** p. 1 (1953).

(4) International Meteorological Organization 1947. Rep of 12th Conference of Directors, Washington (Pu No. 71), Resolution 7, p. 42.

(5) Hull, J. N. *Trans Illum. Engng Soc.*, **19,** p. 21 (1954).

(6) Canham, A. E. *Trans Illum. Engng Soc.*, **19,** p. 2 (1954).

(7) Preston, J. S. *Rev. Opt.*, **27,** p. 513 (1948).

(8) Wallace, R. H. *Plant Physiology*, **12,** p. 647 (1937).

(9) Giovanelli, R. G. *J. Sci. Instrum.*, **30,** p. 326 (1953).

A capacitance-resistance hygrometer

By C. L. Cutting, B.Sc., Ph.D., and A. C. Jason, B.Sc., Ph.D., Torry Research Station, Department of Scientific and Industrial Research, and J. L. Wood, M.A., Ph.D., Sir John Cass College, London, E.C.3

[*Paper first received* 13 *April, and in final form* 23 *July*, 1955]

A new type of hygrometer is described. Indications of relative humidity are given by changes of the electrical properties of anodized aluminium oxide layers. The calibration is independent of temperature from 0 to 80° C, and of the air speed. The instrument is extremely sensitive, and may be easily adapted for continuous recording and control. A theory accounting for the observations is outlined.

e need for a simple, stable hygrometer which is capable of dicating and recording relative humidity over a wide range conditions has long been recognized. Most indirect struments suffer from such disadvantages as hysteresis, ng-period drift, large temperature coefficients, or high nsitivity to contamination. Although absolute methods, g. chemical or dew-point determinations avoid these defects, ey are not suitable for continuous recording or instrumen- tion. For this it is desirable that the indication of humidity presented directly in the form of an electrical parameter thout the need for complex ancillary equipment. Two rther desirable features for successful instrumentation are at the speed of response be rapid, and that no temperature easurement be required additionally.

It is believed that the instrument described in this paper ssesses a number of these advantages, which are not found gether in other hygrometers. Although the capacitance-sistance hygrometer was originally developed to study rious problems involved in the processing and preservation fish, it was considered to have wider application. For this ason a detailed investigation was undertaken.

The hygrometer consists essentially of a condenser having dielectric a porous film of alumina. It behaves as an ectrical transducer responding to changes of relative imidity by variation of its capacitance and resistance.

GENERAL PRINCIPLES

Porous oxide layers formed on aluminium by anodization acid electrolytes provide, by virtue of their structure, a rge surface area for adsorption. Isotherms for the lsorption of water on to these layers are similar in form those cited for bulk powdered alumina by Taylor(1) d Gregg,(2) and follow a Brunauer, Emmett and Teller uation.(3)

In general it is to be expected that the capacitance of a ndenser formed between two conducting layers would vary th the adsorption of water vapour into the dielectric. The sulting changes in capacitance, most simply calculated on additive(4) basis, would however be relatively small. ven at saturation, the quantity of water contained in the yer could not thus give rise to a dielectric constant greatly ceeding 20.

In fact, on approaching saturation, the apparent dielectric nstants of such porous films are observed often to exceed 00. Indeed on occasion capacitances indicating dielectric nstants greater than 8000 have been observed.

A theory has been put forward to explain these observations d is briefly outlined following the sections describing the incipal features of this anomalous behaviour.

CONSTRUCTION OF HUMIDITY SENSITIVE ELEMENT

Any method of anodizing which yields porous aluminium oxide layers will produce humidity sensitive elements, but, for reasons which will be given, sulphuric acid is to be preferred as electrolyte. The temperature, the concentration of the acid, the current density and the anodizing time may each be varied widely so that, depending on the selection of these variables, a great variety of thicknesses and structures can be produced.(5–8) In the examples given the oxide layers were formed as follows, unless otherwise stated:

material: aluminium rod, 0·158 cm diameter 99·5% pure;
electrolyte: sulphuric acid 17·5% per volume;
temperature: 30° C;
current density: various values from 10 to 120 mA/cm^2 were used;
anodizing time: 30 min;
cathode: stainless steel, lead or aluminium.

The thicknesses of the films thus formed are 0·62 ± 0·02 microns per milliammeter per square centimetre (obtained by micrometer measurement before and after chemically removing the oxide).

Observations of the characteristics of elements formed on aluminium rod of 99·998% purity and on high-duty aluminium-alloy wire show that there is no critical dependence on the purity of the aluminium.

Rods may be anodized either singly or in groups. Great care should be taken to degrease them in an organic solvent beforehand. After removal from the electrolyte, the rods are thoroughly washed and then allowed to soak for several hours in distilled water. Details of the succeeding stages in the construction are shown in Fig. 1. The untreated aluminium surface of each rod A is insulated with "capping solution" B which is made to overlap the oxide surface G for about $\frac{1}{2}$ mm. A thin layer of a porous conducting material C is deposited on the oxide and extended over the insulation so that electrical connexion may be made to it by winding a few turns of fine copper wire D round the overlap. These turns are coated with a thick layer of Aquadag E and, after this has dried, the connexion is secured with a little Perspex cement F. The element is then in the form of a robust "probe" which can be handled without fear of breaking the connexion to the outer conducting layer. This layer is most conveniently formed by painting on to the oxide a thin coating of Aquadag which has been diluted three or four times with distilled water. However, provided that the conducting layer is porous, it may consist of chemically deposited silver or, preferably, of an evaporated metallic film.

An element need not take the precise form described and may be of any shape or size as long as the resistance of the conducting layer is low. (For example, an element may be constructed of a 30 s.w.g. aluminium alloy wire, the sensitive portion having an area of less than 1 mm^2.) Whatever the form of construction, it is essential that the connexion to the conducting layer be made as described; otherwise if connexion is made by contact over the oxide surface itself, water vapour becomes trapped at high humidities and this leads to slow response and apparent hysteresis. It is advisable not to extend the conducting layer to those parts of the anodized surface formed on sharp edges in order to reduce the vulnerability to mechanical damage.

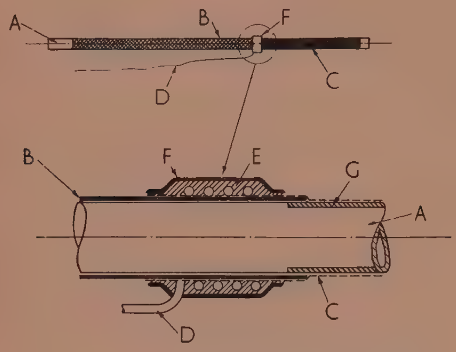


Fig. 1. Construction of hygrometer

CALIBRATION

(i) *Vapour pressure and temperature control.* Any of the well-known methods for calibrating hygrometers$^{(9)}$ may be used, at room temperature. For the purpose of providing a steady stream of air containing water vapour at any desired vapour pressure and temperature, an open-circuit, two-temperature method$^{(10)}$ is convenient. An arrangement of this method which is suitable for calibrating probes is shown in Fig. 2. Air is fed into a saturator *A*, containing filter paper *B* dipping into a pool of distilled water *C*. This is surrounded by a jacket *D* through which water circulates at a temperature t_1 indicated by a thermometer *E*. The water bath is maintained at a temperature $t_2 (\geqslant t_1)$ by the contact thermometer *F* operating a heater *G* through a suitable relay. *H* is a stirrer motor. Air, saturated at temperature t_1, is conducted through a serpentine tube *J* to tubes *K* containing elements *L*. These are supported by tightly fitting corks in holders *M* sealed into the system inside tubes *N* by standard taper glass joints *O* and mercury *P*. The relative humidity in the tubes *L* is given by the ratio of the saturated vapour pressures at t_1 and t_2. The serpentine tube is introduced between the saturator and the elements to ensure temperature equilibration of the air stream. The elements are held entirely beneath the surface level of the water so that their temperature is equal to that of the bath. The anodized areas are situated well down in the tubes *K*, where they are continuously swept by a flow of vapour.

(ii) *Capacitance and resistance measurements.* In principle, almost any alternating current bridge method involving phase balance may be employed. The parallel resistance method, and the series resistance method, both described by Hague were used. In both arrangements the balance is independ of frequency. Small inaccuracies resulting from st capacitances and self capacitances of the bridge compone are negligible compared to the increases of capacitance to measured. Lead capacities are normally negligible but i sometimes necessary to apply a correction when rem measurements involve lengthy leads.

Except in the section dealing with frequency effects, bridge measurements given were obtained at 1000 c/s.

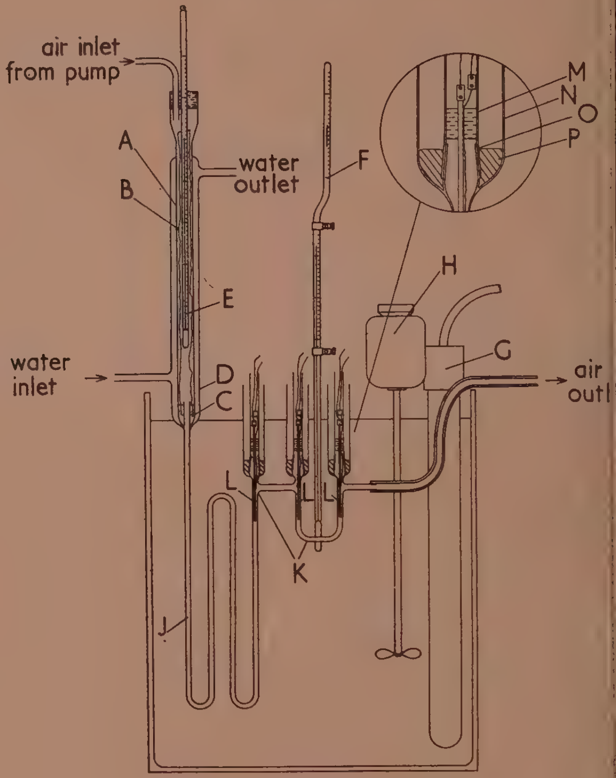


Fig. 2. Open-circuit, two-temperature method fo calibrating hygrometers

EFFECTS OF WATER VAPOUR ON CAPACITANC AND RESISTANCE

Fig. 3 provides an illustration of typical measurements the equivalent parallel capacitance C_p, and resistance R_p, an element at various relative humidities. The readings we all made at a constant temperature t_2 of 30° C.

The form of the dependence of C_p and R_p on relati humidity is determined primarily by the conditions employ in anodizing and the frequency at which measurements a made, and accord with the predicted theoretical behavic discussed below.

In Fig. 3 the points plotted for increasing humidity (ringe and decreasing humidity (unringed), between 0 and 90 relative humidity, show that any effects due to hysteresis the sorption of water by the oxide film are less than th due to the scatter of the points themselves. The measu ments were made at periods from 10 min to 12 h after change of relative humidity. However, if 90% r.h. w exceeded for more than about 10 min hysteresis in ection of increased capacity was observed on decreasing humidity. The adsorption of water by alumina also ows a considerable positive hysteresis at high humidities. is therefore not surprising that the hygrometer characteristics lect this effect to a certain degree.

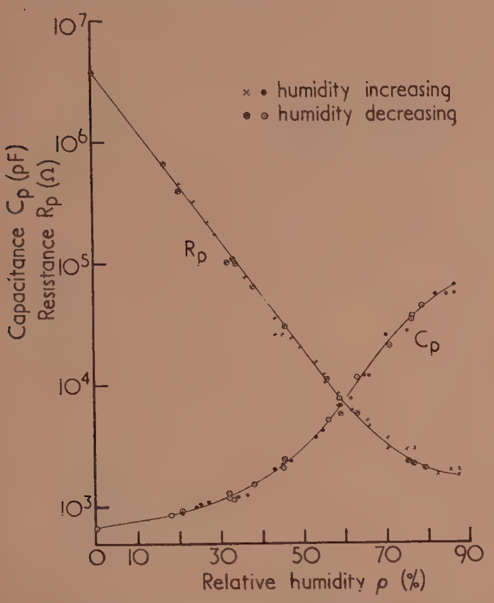


Fig. 3. Variation of equivalent parallel capacity and resistance with relative humidity

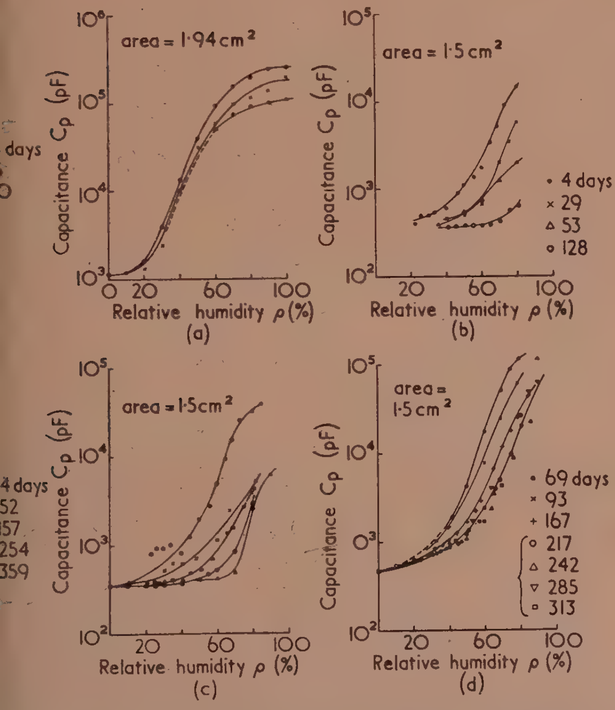


Fig. 4. The effect of aging on the capacitance isotherms of elements anodized in various electrolytes. Capacitance measured by ballistic method at 100 s^{-1}

(*a*) Initial effect for an element anodized in sulphuric acid.
(*b, c, d*) Long-term effects for an element anodized in chromic, oxalic and sulphuric acids.

AGEING AND REPRODUCIBILITY

In the few months immediately after formation, ageing occurs which results in a reduction of C_p and an increase in R_p at any given humidity. These effects are initially very rapid, but the rate of change soon becomes small, and after some time (see Fig. 4) the isotherms do not change further. This figure shows the effect of ageing on the capacity of elements formed in various electrolytes. When there is no further change with time, only those formed in sulphuric acid are sensitive over a wide range of relative humidity. This is the reason for preferring sulphuric acid for the electrolyte in anodization.

It should be noted that the capacitances presented in Fig. 4 were obtained ballistically by the repeated charging and discharging of the condenser.

When a number of elements are prepared by anodizing the batch simultaneously, their capacitance characteristics are comparable. Thus for such a group of five samples, the indication of relative humidity showed a standard deviation from the mean calibration of 3·4% over the entire range from 0 to 90% r.h.

INFLUENCE OF TEMPERATURE

A typical example of the influence of temperature on the capacitance and resistance characteristics of an element is illustrated in Figs. 5 and 6. The most important feature revealed in these figures is that, in the range of temperature investigated (20–80° C), capacity and resistance are each functions of relative humidity rather than of vapour pressure. Although the scatter is here rather greater than in Fig. 3, there are no systematic variations with temperature.

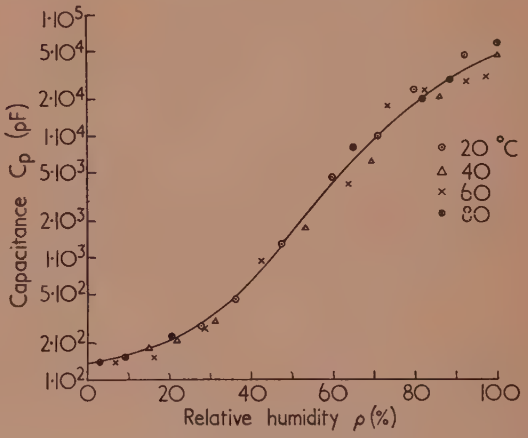


Fig. 5. Influence of temperature on the capacity characteristics of an element

material: element No. 190/1; pure aluminium rod.
electrolyte: sulphuric acide 17·5% per volume.
temperature: 40° C.
current density: 120 mA/cm².
anodizing time: 30 min.
anodized area: 0·61 cm².

As a consequence of the theory discussed later, it was anticipated that at temperatures below 0° C, a marked change in the characteristics would be found. For this reason, the investigation of the effect of temperature was at a later date extended to the sub-freezing point range. Figs. 7 and 8 show that the characteristics remain substantially constant down to a temperature of -15° C, but that a sharp change in these curves occurs before -30° C is reached.

At temperatures above 100° C the elements still show sensitivity to changes in relative humidity; even at 400° C both capacitance and resistance are found to vary with the relative humidity. However, it appears probable that exposure of elements to these higher temperatures causes irreversible changes in the room temperature characteristics.

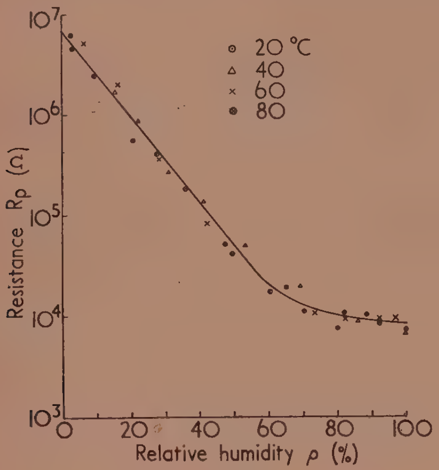


Fig. 6. Influence of temperature on the resistance characteristics of an element. (Conditions identical with those for Fig. 5)

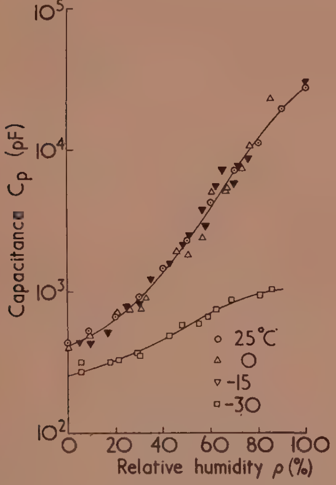


Fig. 7. Variation of capacitance with relative humidity at lower temperatures

TRANSIENT RESPONSE

The response of the capacitance of a typical element to rapid changes in the relative humidity is presented in Fig. 9. The times indicate the period elapsed after transference from the first relative humidity shown, to the second. These humidities were provided by constant humidity bottles. Measurements, made by the ballistic method (repetition rate 100 s^{-1}), are given in terms of galvanometer current. Analysis of the kinetics of surface adsorption(12) shows that water molecules are usually rapidly sorbed on to surfac and the mean time taken to penetrate into the pores of aluminium oxide film is probably less than a second. This compatible with the short response time of the elemer shown in Fig. 9 and with the assumption made in the theo that the effects described are dependent on the surfa conduction along the pore sides.

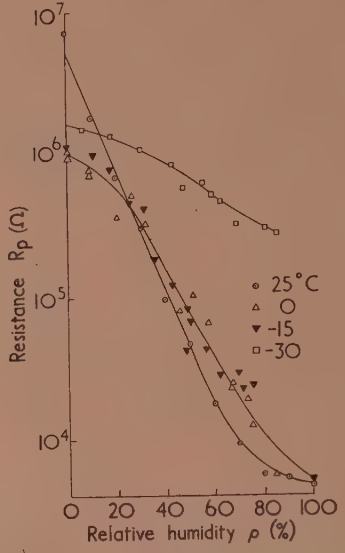


Fig. 8. Variation of resistance with relative humidity at lower temperatures

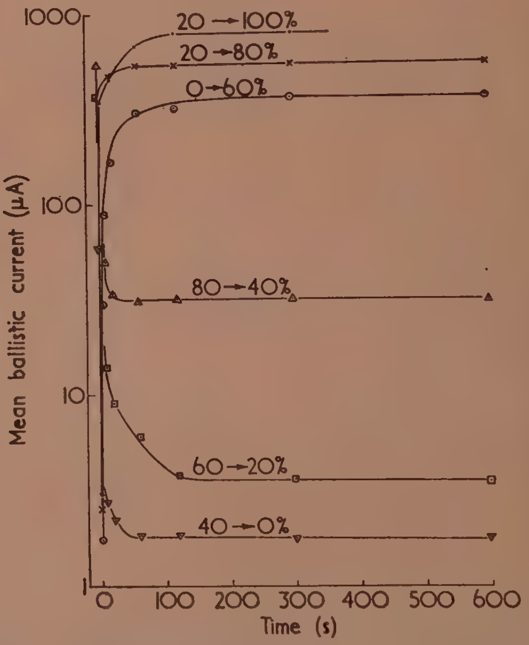


Fig. 9. Response characteristics of an element anodized in sulphuric acid

THEORY

The principal requirement of any theoretical treatment to account for the remarkably large variation of the capa tance of the porous oxide layers as the humidity increas oward saturation. The dielectric constant, based on the istance d between the two conductors (Fig. 10), together ith the area and measured capacitance, may rise to a value f more than 1000 (see earlier section on general principles). uch a large value could not be accounted for by any geo-etrical disposition of the adsorbed water, nor by any easonable modification of the dipoles of the adsorbed water

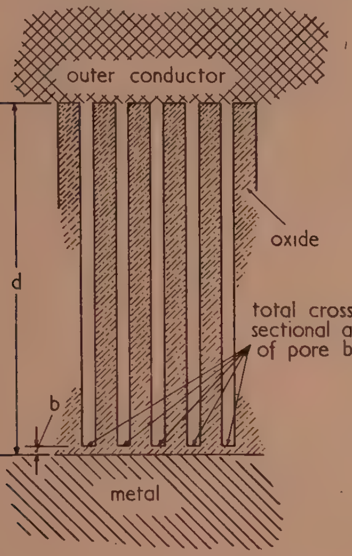


Fig. 10. Pore structure

olecules. An explanation is however provided by the bservation that the capacitances of porous oxide layers easured *in situ* in the anodizing bath are very high. The lectrolyte penetrates the pores, so that this outer conductor hen follows the contours of the oxide surface. Between the ase of each pore and the metal there is a very thin layer of lumina ($b \simeq 120$ Å). The contribution of these pore bases o the capacitance is therefore large. A calculation may be imply made by considering the pores to be cylindrical. stimating from electron micrographs that the cross-sectional rea s at the base be 10% of the superficial area, the apacitance of the pore bases in a 3 cm long rod sample is 3000 pF. This figure is based on a dielectric constant of 2·0 for alumina.

With oxide layers mounted as described in an earlier ection, the capacitances observed at relative humidities pproaching saturation are of this magnitude. This suggests hat as the humidity increases, water is progressively adsorbed n the walls of the pores. The resistance R_1 down the walls ecreases, becoming very small at saturation. The observed capacitance thus changes from that of a condenser, distance d between plates ($C_0 \sim 400$ pF) when dry, to that of a condenser with the outer conductor following the oxide surface ($C_2 \sim 53\,000$ pF) at saturation.

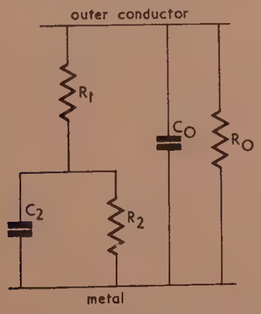


Fig. 11. Equivalent circuit of a single pore

The observed characteristics may be quantitatively accounted for on this basis. The equivalent circuit of the porous layer based on this model is shown in Fig. 11. In addition to R_1, C_0 and C_2, as above, R_2 is the leakage resistance through the pore base. The leakage through the entire thickness d of the oxide is negligible at the frequencies used in the measurements. The equivalent parallel capacitance and resistance of a pore are then

$$C_p = C_0 + \frac{C_2R_2^2}{(R_1 + R_2)^2 + 4\pi^2 f^2 R_1^2 R_2^2 C_2^2} \qquad (1)$$

$$R_p = \frac{(R_1 + R_2)^2 + 4\pi^2 f^2 R_1^2 R_2^2 C_2^2}{R_1 + R_2 + 4\pi^2 f^2 R_1 R_2^2 C_2^2} \qquad (2)$$

For the entire layer two formally identical equations result, the symbols then referring to the oxide layer as a whole. It is now assumed that the variation of R_2 and C_2 with relative humidity is negligible compared with that of R_1. If it were possible to measure R_1 directly at each relative humidity, the isotherms for R_p *versus* relative humidity and for C_p *versus* relative humidity could be predicted. However, as this is not possible, R_1 is obtained from the measured value of R_p [equation (2)], at each relative humidity, and from these the capacity isotherm calculated. An example is shown in Fig. 12. For comparison, C_p, the capacity which would be expected in the absence of the pore effect, is shown on the same scale.

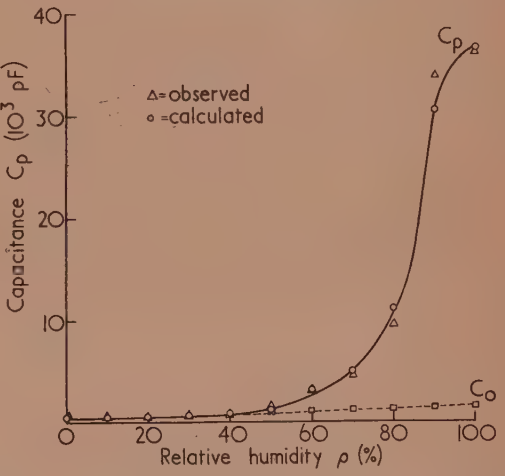


Fig. 12. Calculated and observed values of C_p obtained from measured values of R_p

$C_2 = 40 \times 10^3$ μF.
$R_2 = 2530$ Ω.

SOME CONSEQUENCES OF THE THEORY AND THEIR EXPERIMENTAL VERIFICATION

It will be noticed that the sensitivity of C_p to changes in humidity is greatest at intermediate relative humidities. The theory above suggests that by modifying the length d of the pores, the maximum sensitivity range may be altered. Thus by choosing anodizing conditions to give a small thickness d, the resistance R_1 will become small at lower relative humidities. The greatest sensitivity will then be in this range, while at high humidities C_p will be approximately $C_2 + C_0$, and will not greatly vary. By making d large, the maximum sensitivity will be shifted to higher humidities. The three isotherms shown (Fig. 13) illustrate this effect.

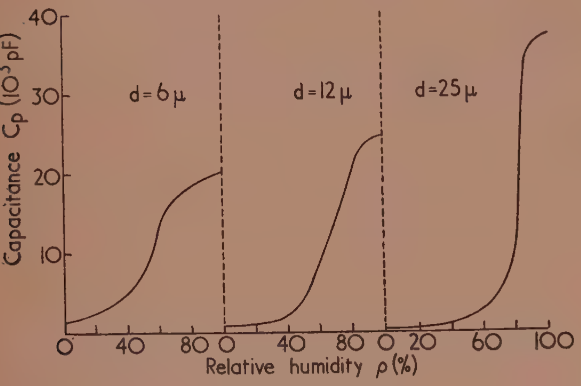


Fig. 13. Effect of oxide film thickness on C_p isotherm

A number of other observations have been made which confirm the mechanism put forward here. Thus oxide layers formed in other acid electrolytes also show the effect. Such layers are porous. In contrast, layers formed in neutral electrolytes, which are nonporous, show no great variation of capacity or resistance with humidity changes.

The effect should be independent of the nature of the outer conductor, provided this does not penetrate the pores. The Aquadag graphite particles are greater than 1000 Å in diameter and so cannot enter the pores (diameter ~ 120 Å). We have found similar isotherms when the outer layer is formed of evaporated aluminium. Minor changes in the outer conductor, due to damage, or repainting with Aquadag, do not impair the functioning.

The adsorption of water vapour on alumina follows a Brunauer, Emmett and Teller equation,(3) so that the quantity of water adsorbed is a function principally of the relative humidity, and comparatively independent of temperature. R_1 is highly dependent on this quantity of adsorbed water (i.e. in the typical isotherm, Fig. 12, the calculated values of R_1 vary from 160 Ω to 20 MΩ). In comparison, the dependence of R_1 on temperature appears to be small. This accounts for the observation that the isotherm characteristics in the range 20–80° C show no noticeable dependence on temperature, provided comparison is made on a relative humidity scale. Further, this interpretation suggests that a phase change of the adsorbed water, by markedly affecting R_1 would result in a sharp change in the isotherms. Such an abrupt alteration in the temperature sensitivity has in fact been found between −15 and −30° C (Figs. 7 and 8). Further work is in progress at the Torry Research Station on the low temperature characteristics, which will provide a more detailed knowledge of the phase transition of the adsorbed water.

Effect of frequency. The resistance R_L along the length of the outer conducting layer of an element is normally not negligible. If the layer consists of Aquadag for example, this resistance is usually about 1000 Ω/cm. The element is thus equivalent to an open ended transmission line. In deriving equations (1) and (2) no account was taken of this finite outer conductor resistance. When this is taken into consideration the resulting impedance X_0 of the element equal to $\sqrt{(R_L X)} \coth \sqrt{(R_L/X)}$, where $1/X = 1/R_p$ $2\pi f i C_p$.(13) The bridge measures the two components of X

Provided R_L is small compared with $|X|$, X_0 is close equal to X. However, at higher frequencies this is not s From equations (1) and (2), it is apparent that C_p and R both decrease as the frequency increases, and ultimately |X becomes comparable with R_L.

By making R_L extremely small, $X = X_0$ so that the bridg readings at higher frequencies would then give R_p and C directly. This was effected by forming the porous oute conductor of evaporated aluminium on which was wound spiral of 1 mm pitch of 40 s.w.g. aluminium wire. Th reduced the effective value of R_L to less than 1 Ω. Capac tance and resistance measurements, made on this element i the range of frequency from 50 c/s to 10 kc/s at selecte relative humidities from 0 to 100% at 20° C, are shown i Figs. 14 and 15. It will be noted that C_p and R_p decreas

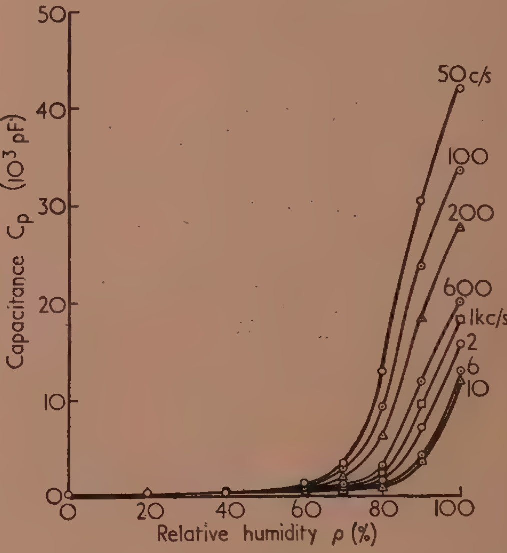


Fig. 14. Effect of frequency on capacity C_p of oxide layer

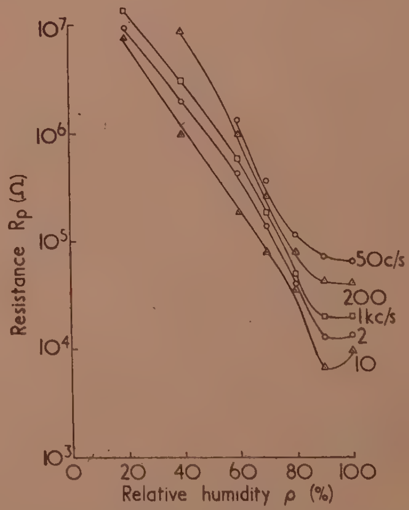


Fig. 15. Effect of frequency on resistance R_p of oxide layer

ith increasing frequency at all relative humidities, as pected from equations (1) and (2). The results are in antitative agreement with these equations, the constants $_2$ and R_2 being dependent on the frequency.

A notable consequence of the combination of equations (1) d (2) is that at higher frequencies R_p should pass through minimum as the humidity tends toward saturation, while $_p$ continues to increase. This has indeed been found for l frequencies greater than 1 kc/s.

If elements with Aquadag outer conductors are used at gher frequencies, the transmission line effect results in the easured parallel capacity being less than C_p, while the easured parallel resistance is greater than R_p. This has een directly confirmed by preparing two elements anodized multaneously; one with an evaporated aluminium outer yer, the other with Aquadag.

Effects of other vapours. It is appropriate to mention here at the effects of other vapours on the elements are con-stent with the influence of their conductivity in the condensed ase on R_1, the pore side resistance.

DISCUSSION

It is evident from the data presented that the hygrometer is pable of measuring relative humidity with considerable recision (see Fig. 3, where the mean deviation is less than r equal to ±2·0% r.h.) over a wide range of operating onditions. The instrument is considered to offer the follow-g advantages: (*a*) the characteristics are almost independent f temperature from 0 to 80° C; (*b*) elements anodized multaneously have the same calibration curve, if due care taken in their construction; (*c*) the characteristics may be onveniently modified by a suitable choice of anodizing onditions; (*d*) the hygrometer displays the humidity in terms f electrical parameters convenient for continuous recording nd control; (*e*) the physical size and shape of elements may e widely varied to suit particular applications; (*f*) the elocity of the air stream flowing past the instrument does ot affect the readings; (*g*) remote readings are possible;) the response time is relatively rapid; (*i*) after the initial eriod of aging, the calibration is stable, provided no major hemical contamination occurs; (*j*) the elements are reason-bly robust and not unduly sensitive to physical shock.

As considerable interest has been shown in the use of these lements for purposes of recording and control of relative umidity, the following examples of our experience are given.

Instrumentation of the hygrometer for purposes of con-inuous recording is easily carried out by utilizing the ballistic apacity method. In this way both anodized plates and rods ave been used to provide a continuous record of the tmospheric humidity.

The humidity in cold stores has been similarly recorded. mong trial industrial applications has been the continuous easurement of relative humidity in the intergranular spaces f phosphate fertilizer emerging from a dryer on a moving elt: the relative humidity was found to provide an approxi-ate indication of the dryness of the product.

A wind tunnel of cross-section approximately 3 ft^2, used for air-drying experiments, has had its relative humidity at air speeds up to 20 ft/s kept constant within ±0·25%.

The instrument suffers from the following disadvantages: (*a*) At relative humidities of 90% or more the response is slow, and there is a small irreversible drift. This gives rise to positive hysteresis on returning to lower relative humidities Further prolonged exposure to saturation destroys the sensitivity of the element. (*b*) Applied voltages greater than 80% of the final formation voltage cause temporary electrical breakdown in the oxide. (*c*) Contamination by surface migration of oil or grease prevents the instrument functioning.

It is concluded that provided precautions are taken to avoid these conditions, the instrument is a useful hygrometer. Work on further development, in particular a detailed investigation of the ballistic method, is in progress.

ACKNOWLEDGEMENTS

The work described in this paper was carried out as part of the programmes of the Food Investigation Organization of the Department of Scientific and Industrial Research, and of the Sir John Cass College.

The authors wish to acknowledge the assistance of Mr. R. R. Haddow and Mr. A. Lees who carried out much of the experimental work.

REFERENCES

(1) Taylor, H. S. *J. Amer. Chem. Soc.*, **56**, p. 1685 (1934).

(2) Gregg, S. J. *J. Chem. Soc.*, p. 563 (1946).

(3) Brunauer, S. *Adsorption of Gases and Vapors*, equation (37), p. 153 (Princeton: Princeton University Press, (1943).

(4) Böttcher, C. J. F. *Theory of Electric Polarization*, equation (6.45), p. 188 (London: Elsevier Publishing Co., 1952).

(5) Zauscher, H. von. *Ann. Phys.* [*Leipzig*], **23**, p. 597 (1935).

(6) Napier, D. H., and Westwood, J. V. *Met. Ind.*, **76**, p. 123 (1950).

(7) Bahn, R., and Böttcher, O. *Z. Phys.*, **135**, p. 376 (1953).

(8) Charlesby, A. *Proc. Phys. Soc.* [*London*] *B*, **66**, p. 317 (1953).

(9) Wexler, A., and Brombacher, W. G. *Nat. Bur. Stand.*, Circular 512 (1951).

(10) Cutting, C. L., and Jason, A. C. *J. Sci. Instrum.*, **30**, p. 338 (1953).

(11) Hague. *A.C. Bridge Methods*, 4th ed., pp. 329 and 335 (London: Sir Isaac Pitman and Sons Ltd., 1938).

(12) De Boer, J. H. *The Dynamical Character of Adsorption*, p. 30 (London: Oxford University Press, 1952).

(13) Smythe, W. R. *Static and Dynamic Electricity*, 2nd ed., p. 377 (London: McGraw-Hill Book Co. Ltd., 1952).

The behaviour of humidity-sensitive capacitors at room temperature

By C. R. Underwood and R. C. Houslip, Environmental Hygiene Research Unit, Medical Research Council Laboratories, London, N.W.3

[*Paper first received* 8 *February, and in final form* 2 *May*, 1955]

Measurements of the humidity in small enclosed spaces are not easily performed with the conventional types of hygrometer, but the capacitance hygrometer developed by Jason enables such measurements to be made. An investigation of the behaviour of the hygrometer at room temperatures was carried out using a divided-flow apparatus and a sensitive dew-point hygrometer. The capacitance hygrometer responded to changes in both temperature and humidity, and an empirical equation relating the impedance of the instrument (measured at 1 kc/s), the air temperature, and the water-vapour pressure, was found. The response of the hygrometer to changes in water-vapour pressure was found to depend on the frequency of the applied potential difference, the sensitivity decreasing as the frequency was increased. The hygrometer followed changes in humidity very rapidly so long as the relative humidity was less than about 80%. At higher relative humidities the response was slow.

It was concluded that the behaviour of the instrument was consistent with the adsorption of water-vapour on the dielectric material. The opinion is expressed that the instrument may be of considerable value for measurements in small spaces.

Measurements of the humidity of the air enclosed in small spaces are often required in research and industry. For example, the gradient of water-vapour pressure between the skin and the surrounding air is of interest to the physiologist engaged in studying the heat regulation of the human body and the properties of various assemblies of clothing.

The classical methods usually employed for the measurement of humidity are not readily adapted to these circumstances. They are not easily modified to provide continuous records, or readings at a point remote from the atmosphere under examination.

The effects of water vapour on the electrical properties of anodized aluminium were noticed by Ansbacher.(1) They were further investigated by Jason,(2) who has developed a hygrometer which relies for its action on changes in the dielectric constant of the metallic oxide when this is exposed to atmospheres of varying water content. During the early stages of development Jason had suggested that the hygrometer would be of use for the purpose mentioned above, and it was decided to examine its behaviour under the conditions likely to be of interest. With this in view a continuous, divided-flow apparatus for the production of atmospheres of known humidity was constructed. There follows a description of the apparatus, an account of the methods used and of the results obtained.

APPARATUS AND METHODS

Hygrometers. Two types of hygrometer were used in this investigation, differing only in the method by which anodizing was performed. The construction of the hygrometer is shown in Fig. 1.

The hygrometer takes the form of a capacitor. It consists of a few inches of aluminium rod of $\frac{1}{8}$ in. or $\frac{1}{16}$ in. in diameter, one end of which is coated, for a length of about 1 in., with a layer of aluminium oxide deposited by anodic oxidation. This layer is coated in turn with a film of colloidal graphite (Aquadag). Connexion to the graphite film is made by binding on a few turns of copper wire and applying a further thin coating of graphite. The exposed aluminium shank is insulated by means of a plastic sleeve, over which is wrapped the free end of the wire, and the wire is secured by a further plastic covering. Electrical connexions are made to the exposed shank and the wire. Thus the capacitor ha the rod and the graphite layer as plates and the aluminiu oxide as dielectric.

Anodizing of the earlier type of instrument was carrie out in a solution containing 3% by weight of oxalic aci using a carbon cathode, with a potential difference of 60 across the cell. The thickness of the layer was controlle by varying the time during which current was passed anodizing was carried out for periods of from 10 to 30 mi After anodizing, the rod was thoroughly washed in distille water and when dry was coated with graphite.

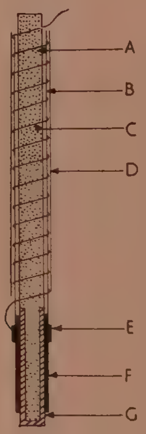


Fig. 1. The construction of a Jason hygrometer

A, aluminium rod; *B*, plastic layer; *C*, thin copper wire; *D*, plastic insulator; *E*, graphite covered connexion; *F*, graphite layer; *G*, anodized layer.

The more recent form of the instrument was prepared i a similar manner, but the anodizing was carried out in solution containing 17% of sulphuric acid.

The divided-flow apparatus. A diagram of the divided-flo apparatus is shown in Fig. 2.

Atmospheric air was drawn into the system through a pip which divided into two branches of equal cross-sectional area One branch conveyed air to a saturator containing numerou glass beads and distilled water, the temperature of whic ould be raised by means of an overwound electric heater. n its passage through the saturator the air took up a large uantity of water vapour, together with some spray which vas removed by a filter. The humid air was then delivered o one side of a three-way valve.

The other branch of the incoming pipe supplied air to a essel containing silica gel which removed most of the water resent, and the remainder of the water was extracted by assing the partially dried air through a copper coil immersed n a mixture of solid carbon dioxide and propyl-alcohol. The ry air was delivered to the other side of the three-way valve. This valve allowed the proportion of humid to dry air flowing n the system to be adjusted. Uniformity of mixture was nsured by passing the combined air streams into a mixing hamber the outlet of which was taken, *via* a long pipe, to test chamber. The temperature of the air entering the test hamber could be increased by adjusting the current flowing hrough an electric heater wound over the outside of the ong pipe. Airflow through the apparatus was maintained y means of a pump which exhausted to atmosphere. etween the pump and the test chamber was a large reservoir, hich served to smooth out pressure pulsations due to the ump.

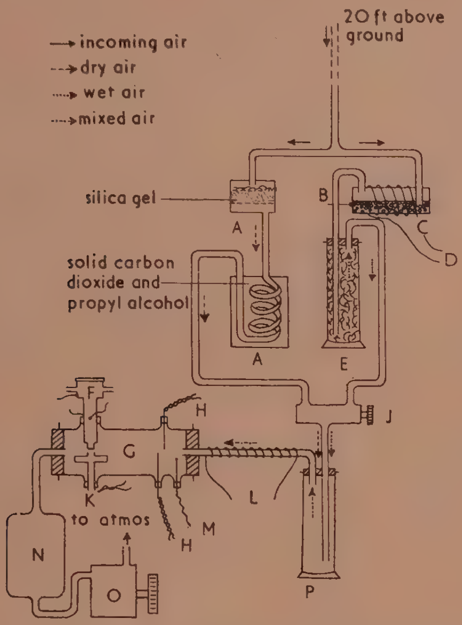


Fig. 2. Diagram of the divided-flow apparatus

A, dryer; *B*, thermometer; *C*, saturator; *D*, overwound heater; *E*, spray trap; *F*, hygrometer; *G*, test chamber; *H*, element; *J*, valve; *K*, photocell in holder; *L*, heater; *M*, thermocouple; *N*, reservoir; *O*, pump; *P*, mixing vessel.

In order to avoid possible contamination, the air inlet to he apparatus was taken from a point some 20 ft above round level. It was assumed that effects due to normal tmospheric pollution could be neglected, since the laboratory s situated in a residential area some 400 ft above sea level.

The test chamber. The test chamber consisted of a length f glass tube, of 3 in. bore, with side arms. Mounted in the rms were a Nichrome-Eureka thermojunction for the easurement of air temperature, the hygrometers under xamination, a dew-point hygrometer and a photoelectric ell. The dew-point hygrometer, which was situated downtream of the test hygrometer elements and the thermocouple, was used to measure directly the dew point of the air flowing in the test chamber.

The dew-point hygrometer. The dew-point hygrometer was specially constructed for this investigation. It consisted of a Polythene tube which was screwed to a brass reservoir. The lower end of the tube carried a small brass thimble, with a thin, flat, highly polished silver mirror as its base. The temperature of the thimble was raised by means of a small electric heating coil wound externally, and lowered by the evaporation of the ether with which the tube and reservoir were filled. The rates of heating and cooling were regulated by varying the current which passed through the heater, and the volume of air drawn through the ether. Thus, by careful adjustment, the temperature of the thimble was maintained at any desired level, and measured by means of a Nichrome-Eureka thermocouple one junction of which was embedded in the surface of the mirror.

The dew-point hygrometer was mounted vertically in one of the side arms of the test chamber. A 48 W lamp, mounted in a housing fitted with lens and iris, enabled an intense parallel beam of light to be directed through the wall of the chamber on to the mirror at such an angle that the reflected beam was absorbed by the blackened rear wall of the chamber. A photoelectric cell, screened so as to receive only light scattered from the mirror, was mounted beneath the thimble. Deposition of dew on the mirror increased the intensity of the light scattered on to the photoelectric cell and the output from the cell was amplified and displayed by means of a microammeter.

Measurement of the capacitances of the hygrometers. The series capacitances and resistances of the hygrometers were measured by means of a Schering bridge. The capacitances shown in the various figures and the table are the series capacitances. The values of shunt resistance quoted were obtained by computation from the bridge readings. The bridge was energized from a variable frequency oscillator, and the output taken to a bridge amplifier tuned to the source frequency. This amplifier, constructed to a design of Scroggie,(3) gave an indication of balance on a milliammeter, and also an audible response through a loudspeaker. Measurements were normally carried out with a source frequency of 1000 c/s.

Measurement of air temperature. The temperature of the air flowing in the test chamber was determined with the aid of a Nichrome-Eureka thermocouple, employing two cold junctions immersed well beneath the surface of melting ice. Specimens of the wire, which was also used for dew-point measurements, were submitted to the National Physical Laboratory for e.m.f.-temperature calibration. The e.m.f.'s corresponding to the air temperatures and dew points were measured by means of a direct-reading potentiometer.

Measurement of dew point. The temperature of the hygrometer thimble was slowly lowered, until a deflexion of the photocell amplifier meter showed that dew had commenced to form on the mirror, and the temperature at which this occurred was noted. The temperature was then raised by adjusting the cooling rate, or if necessary applying heat, until the film of dew began to disappear, and the temperature of the thimble was again noted. The process of alternate cooling and heating was continued until a fine film of dew of constant thickness, represented by a small steady reading of the meter, was established. The steady temperature under these conditions was taken to be the dew point. When the dew point was below freezing point care was taken to ensure that the dew was in fact frozen and was not supercooled.

RESULTS

Initial experiments. In some early attempts at calibrating hygrometers whose dielectric was formed in oxalic acid solution, the temperature of the air flowing in the apparatus was not controlled although it was noted when each capacitance reading was made. It was apparent that an increase in air temperature resulted in a decrease of measured capacitance with a fixed value of vapour pressure, and all further experiments were therefore carried out with the temperature of the circulating air under control.

In subsequent experiments it was found convenient to hold the vapour pressure constant and to vary the temperature. In this way isobars showing the variation of both the capacitance and shunt resistance of the hygrometer with temperature were plotted, and these curves were then used to obtain isotherms representing the variations with vapour pressure for several levels of temperature.

Such isotherms determined for hygrometers of the oxalic-acid type showed clearly the decline in sensitivity with increase of temperature, and it was also evident that the effect of temperature was greatest at the higher vapour pressures. These results were obtained with freshly prepared hygrometers, but later calibrations showed a considerable loss in sensitivity. It was therefore decided to abandon the hygrometers prepared in the oxalic acid anodizing bath, and to use some prepared in sulphuric acid. Dr. Jason kindly provided a supply of this latter type, which had been allowed to age for several months, and the results given below were obtained with these hygrometers.

Behaviour of hygrometers prepared by anodizing in sulphuric acid solution. Isotherms showing the variations of capacitance and shunt resistance with vapour pressure are given in Figs. 3 and 4.

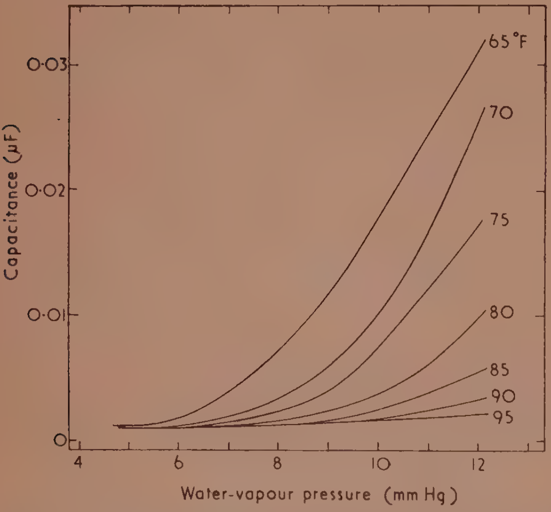


Fig. 3. Isotherms showing the change of capacitance with water vapour pressure for a hygrometer prepared by anodizing in a sulphuric acid solution

It is clear that capacitance is a poor index of the lower vapour pressures, the useful range being diminished by increase in temperature. Shunt resistance on the other hand is a good index at the lower vapour pressures, with a useful response over the whole range of vapour pressures. A combination of these two indices would, if correctly chosen, be a much better index of vapour pressure than either taken singly, and it would be of considerable practica advantage if this combination of resistance and capacity could be measured directly. The impedance of the hygrometer was chosen as such an index.

For a typical hygrometer the values of impedance were calculated from capacitance and series resistance readings

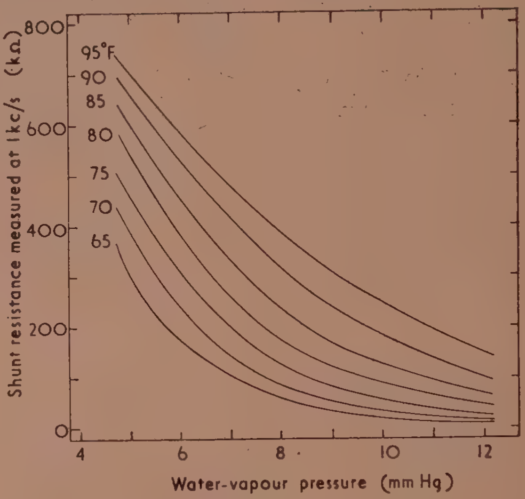


Fig. 4. Isotherms giving the change of shunt resistance with water vapour pressure for a hygrometer of the sulphuric acid type

obtained at 1 kc/s from the Schering bridge, and isotherm showing the variation of impedance with vapour pressur were plotted. These isotherms were sigmoidal in shape, anc they could be represented, within the range of condition investigated, by an empirical equation of the form:

$$Z/Z_{max} = 1/[1 + \exp(\alpha p + \beta p^2 + K)] \qquad (1$$

where Z is the impedance at 1 kc/s in thousands of ohms
p is the water vapour pressure in the test chamber ir millimetres of mercury
α, β and K are constants
Z_{max} is the maximum value of impedance in thousand of ohms to which the sigmoidal isotherms tende as the vapour pressure approached zero.

Within the limits of experimental error Z_{max} was independent of temperature. In practice the value of Z_{max} wa obtained from isobars plotted to show the relationshi between the impedance of the element and the temperature.

In the empirical equation (1) the constant K is clearly function of the temperature. It may be expressed as:

$$K = at + bt^2 + ct^3 + \ldots$$

where a, b, c, etc., are constants.

Within the range of conditions investigated it was foun permissible to neglect all the powers of t in the abov expression after the first, and to write:

$$K = \gamma t$$

where γ is a constant, and t is in degrees Fahrenheit.

Rewriting equation (1) inserting the approximate valu for K:

$$Z/Z_{max} = 1/[1 + \exp(\alpha p + \beta p^2 + \gamma t)] \qquad ($$

In Fig. 5 are shown a series of isotherms calculated from quation (2). The full lines represent the range of conditions vestigated, the dotted lines are extrapolations from quation (2).

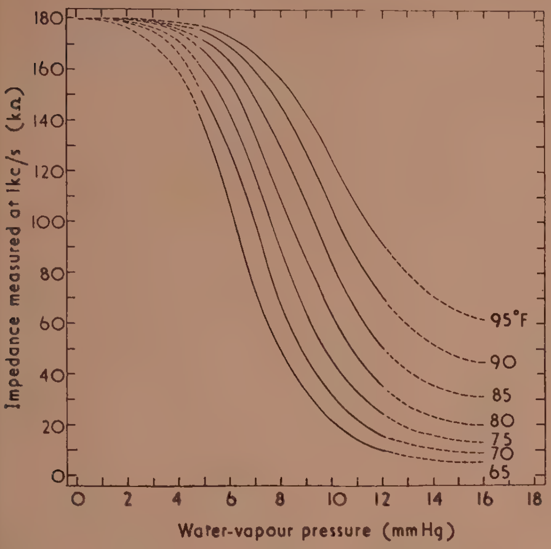


Fig. 5. Isotherms for a typical hygrometer, prepared in sulphuric acid solution, showing the variation of impedance with water-vapour pressure. Full lines represent range of conditions used experimentally

The values of the constants in equation (2) for the hygro- eter whose curves are shown in Fig. 5 were found to be:

$$\alpha = 1\cdot181$$
$$\beta = -0\cdot036$$
$$\gamma = -0\cdot095$$
$$Z_{max} = 180$$

Inserting these values in equation (2) we have:

$$Z/180 = 1/[1 + \exp(1\cdot181p - 0\cdot036p^2 - 0\cdot095t)] \quad (3)$$

Using equation (3), values of vapour pressure were cal- ulated for each observed value of impedance and tempera- re. The root-mean-square deviation between this calculated alue of vapour pressure and the observed vapour pressure as found to be $\pm 0\cdot26$ mm of mercury.

The values of the constants α, β, γ and Z_{max} were found differ for each of the hygrometers examined, although eir orders of magnitude were similar.

Frequency response. As mentioned above, the frequency f the bridge source was usually adjusted to 1000 c/s, and e bridge amplifier was tuned to this frequency. Some xperiments were, however, performed at frequencies of 50, 00, 500, 1000, 5000, 10 000 and 50 000 c/s, at a temperature f 62·2 ± 0·5° F. The output level of the bridge source as held constant at 1 V r.m.s. and the bridge amplifier djusted to have a flat response for these experiments.

Curves showing the change in measured capacitance for xed values of vapour pressure with the logarithm of the equency are given in Fig. 6, and Fig. 7 shows for several equencies the change in impedance with vapour pressure.

Although the impedance is naturally reduced as the fre- uency increases, it will be observed that the change with apour pressure is diminished as the frequency is increased, ntil at 50 kc/s the response is negligible.

Further limited investigations at a frequency of 50 c/s showed that the results could be expressed by means of equation (2), given above, but the values of the constants α, β, γ and Z_{max} were however modified.

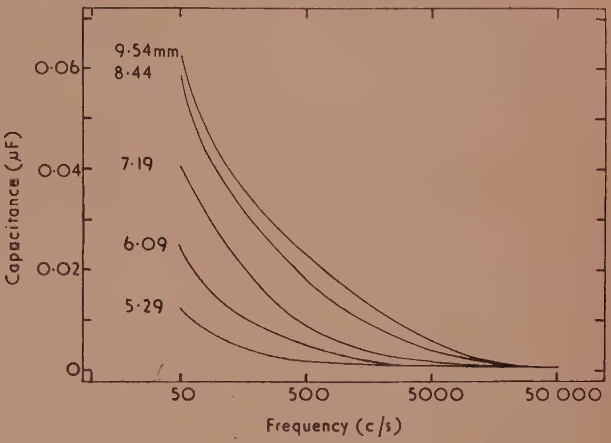


Fig. 6. Curves showing the change in measured capacitance for fixed values of water-vapour pressure with the logarithm of the frequency of the bridge source. Temperature 62·2 ± 0·5° F

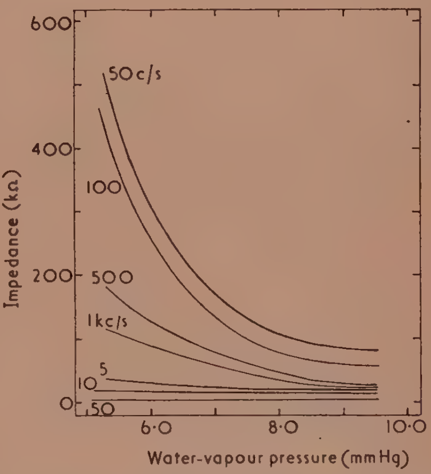


Fig. 7. Graph showing the variation of impedance with vapour pressure for different frequencies at constant temperature. Temperature 62·2 ± 0·5° F

Speed of response. Although the apparatus described above is not ideal for investigating the rapidity with which the hygrometer responds to changes in vapour pressure, it was observed that for small changes the response was extremely rapid, except when the atmosphere was nearly saturated, i.e. above about 80% relative humidity.

A few experiments were performed to obtain further information as to the response time. These were carried out in the following manner. The air in the test chamber was adjusted to a high constant humidity and the dew point noted. The humidity was then lowered as quickly as possible to a lower constant value, and the dew point again measured. The capacitances of the hygrometer were observed during the change, and these are shown in the table. During these experiments the temperature was held constant.

Table showing the changes in the capacitance of a typical hygrometer with time following a rapid change in humidity (temperature 60·7° F, frequency 1 kc/s)

Time (min)	*Capacitance* (μF)	*Remarks*
0	0·0288	Vapour pressure lowered from 10·56 to 4·73 mm of mercury and relative humidity from 78 to 35%.
1·5	0·0020	
3·75	0·0016	
4·75	0·0016	
6·0	0·0016	
6·75	0·0016	
7·75	0·0015	
12·0	0·0015	Vapour pressure raised from 4·75 to 10·91 mm of mercury and relative humidity from 35 to 80%.
15·0	0·0292	
18·0	0·0300	
21·0	0·0304	
28·0	0·0308	

Stability. It is understood that the calibration of a hygrometer element tends to change with time during the first few months after manufacture. The elements used for this investigation were made six months before any measurements were undertaken. The measurements were completed during the ensuing two months, and over this period the results were consistent throughout the range of conditions mentioned above.

When the relative humidity was changed from a low value to above about 80%, the bridge readings became steady after some 15 min. When the change was reversed, however, about 1 hour elapsed before steady readings were obtained.

Unnecessarily high potential differences should not be applied to the capacitors. It was observed that at voltages greater than about 10 V r.m.s. at 50 c/s the dielectric tended to break down, and a partial breakdown caused inconsistent readings.

DISCUSSION

It seems likely that the response of these hygrometers is due to the adsorption of water vapour from the atmosphere by the alumina dielectric of the hygrometer. The very rapid response to changes in vapour pressure when the atmosphere is far from saturated, and the sluggishness of response which occurs when saturation vapour pressure is approached, are consistent with this explanation.

Various equations are available which express the relationship between quantity of vapour adsorbed and concentration. For the equilibrium existing between a porous solid and a surrounding vapour, the concentration is given by the vapour pressure, and here the classical adsorption equations are only applicable over a small range of vapour pressures, becoming less accurate as the vapour pressure increases towards saturation. Isotherms plotted to show the variation of quantity of vapour adsorbed with a wide range of vapour pressures, extending almost up to saturation, are found to be sigmoidal in shape, and various equations describing this behaviour have been proposed for water vapour. We have not attempted to establish any relationship between the quantity of wat adsorbed and the impedance of the hygrometer, but the shap of the isotherms obtained for the hygrometers would see to indicate that a fairly simple relationship between quantit of water adsorbed and impedance does exist.

From the results it would appear that the hygrometer of value in that it permits measurements to be made in co fined spaces, is readily adapted to give remote readings, an will provide an output suitable for continuous recording. is necessary, however, to know the temperature of the atm sphere under examination with some precision. In ou opinion the hygrometer should not be used instead of th conventional types, especially in atmospheres of hig humidity, but it may be of considerable value in the ci cumstances outlined above.

Inspection of the curves of Fig. 5 shows that the change impedance for a given change of vapour pressure increases the temperature falls, suggesting that the hygrometer may hav applications at low temperatures.

It is possible that the hygrometer would be of use to th process-control engineer, since an electrical output may b obtained which is easily amplified and made available f control purposes. If it is to be used in this way it is clearl necessary to have a knowledge of its behaviour over muc wider ranges of temperature and humidity than those covere by this investigation.

The values of impedance quoted were obtained, as has bee mentioned, by calculation from readings made with Schering bridge. In practice it would probably be mor convenient to measure the impedance upon some direc reading instrument.

ACKNOWLEDGEMENTS

The authors wish to acknowledge their indebtedness Dr. A. C. Jason for kindly providing some of his hygr meters, to Mr. F. A. Chrenko for his valuable help in th mathematical expression of the sigmoid curves, to Mr. F. Smith for designing and constructing the three-way mixi valve, to Miss J. A. Stevenson, Miss R. J. Pearse and Mi I. B. Bolton for their help with observations and preparati of drawings. The authors would also like to thank Dr. Bedford for his encouragement at all times.

REFERENCES

(1) Ansbacher, F. The experimental investigation of th effect of electron bombardment on the conductivity insulators. Ph.D. Thesis, University of London (1950

(2) Jason, A. C. Unpublished results. Torry Researc Station Interim Record No. 4, 1953. Available o request from Technical Information and Documen Unit, Cunard Building, 15 Regent Street, Londo S.W.1, or the Superintendent, Torry Research Statio Aberdeen.

(3) Scroggie, M. G. *Wireless World*, **57**, p. 175 (1951).

A d.c. and a.c. balance detector with automatic protection from overload

By C. Morton, B.Sc., Chelsea Polytechnic, London, S.W.3

[*Paper first received* 3 *May, and in final form* 15 *June*, 1955]

By using two junction transistors in a balanced circuit having a current gain of 50 and power consumption of 13 mW, the sensitive galvanometer normally employed as a d.c. null point detector may be replaced by a robust and inexpensive microammeter. The amplifier is so designed that, when an e.m.f. exceeding ±150 mV is applied to its input terminals, the differential input resistance approaches infinity, thus protecting both the transistors and the meter from injury. In order to use the circuit as an amplifying, phase-selective, a.c. balance detector, an auxiliary e.m.f. of about 4 V, of the same frequency as the bridge voltage, is applied to the transistors; a voltage sensitivity of 15 mA/V (r.m.s.), with automatic protection from overload, is then obtainable.

the application of several instrumental methods of chemical nalysis, notably absorptiometry, fluorimetry, and polaro-aphy, it is necessary to detect currents of the order of)$^{-9}$ or 10^{-8} A, usually by means of a reflecting galvano-eter. Damage due to overloads inadvertently applied by nalysts inexperienced in the use of sensitive indicating struments is a troublesome source of expense and incon-enience in teaching institutions and industrial laboratories. 'ith the aid of the junction transistors now commercially vailable, an inexpensive amplifier capable of providing a irrent gain of 50 for a power consumption of a few milli-atts may be constructed, and it occurred to the author that, y taking advantage of the amplification afforded by these evices, it might be possible to replace the delicate galvano-eter by a more robust and less costly detector. Amplifica-on by means of transistors offers the further advantage that ie amplifier is readily transformed into a phase selective, c., null point detector, suitable for use in conductimetric nalysis.

D.C. MEASUREMENTS

Shea(1) has discussed the numerous circuits which have een devised for d.c. amplification by means of transistors, nd has provided a comprehensive bibliography. The main ifficulty encountered in the design of a d.c. transistor ampli-er arises from the marked dependence of the characteristics pon ambient temperature. For this reason, the use of a ngle transistor in the well-known base input circuit, recently iggested by Davidson(2) as a means of amplifying galvano-ieter deflexions, was found to yield unsatisfactory results. everal ingenious but somewhat complicated methods of roviding temperature compensation have been described(1); owever, for the present purpose, it was found that an dequate degree of immunity from drift due to temperature uctuations could be obtained by the use of two junction ansistors in a simple balanced circuit. As transistors are ery susceptible to damage due to transient or sustained over-oads, it was considered essential to design the amplifier in ich a manner as to ensure full protection of both the tran-stors and the indicating instrument.

The circuit which was eventually adopted is shown in a mplified form in Fig. 1. For use as a d.c. null point detector, ie switch S is thrown to the d.c. position; the source V iormally a 4·5 V dry battery) then provides, in addition to ie collector voltage, the bias currents i_3 and i_4 required to djust the transistors T_1 and T_2 to suitable operating points n their characteristic curves. As the input current I due to ie unbalanced voltage E increases, the collector current of ; diminishes and that of T_2 increases; in consequence, an amplified output current I_0 proportional to the input current I flows through a microammeter M connected across resistances r_3 and r_4 included in the collector circuits. In the neighbourhood of the balance point ($I = 0$, $i_3 = i_1$, $i_4 = i_2$), the response to changes in both I and E is linear, a current gain $S_i = \partial I_0/\partial I$ of 50 and voltage sensitivity $S_v = \partial I_0/\partial E$ of 18 mA/V being obtainable. As the unbalanced e.m.f. increases, $i_3 = i_1 - I$ diminishes, passes through zero, and changes sign; when $I > i_1$, the transistor T_1 becomes non-conducting, and the differential input resistance $R_i = \partial E/\partial I = S_i/S_v$ of the amplifier approaches infinity. Similarly, if the input voltage E is reversed in sign and gradually increased, the transistor T_2 becomes non-conducting, and the slopes of the I/E and I_0/E curves fall almost to zero, when $I > i_2$. Thus both the transistors and the microammeter are automatically protected from injury due to overload.

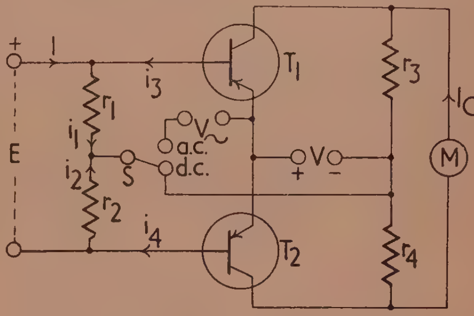


Fig. 1. Basic circuit of detector

A.C. MEASUREMENTS

Under the conditions prevailing in industrial laboratories, a visual indication of the balance point in a.c. bridge measurements is preferable to the use of the telephone, and it is also desirable that the null point detector should possess directional characteristics, i.e. the direction of the deflexion should indicate the sense of the adjustment required to attain balance. Astbury(3) has reviewed the various circuits which have been proposed for this purpose. Unfortunately, the range of application of phase-selective detectors of the thermionic valve type, such as those of Cosens(4) and Stuart,(5) is virtually restricted to measurements at supply frequencies by the requirement that an auxiliary e.m.f. of at least 100–200 V, of the same frequency as that applied to the measuring bridge, must be available. The power consumption of detectors employing full- or half-wave rectifiers(6,7,8) is moderate, but no amplification is provided by these devices.

In order to use the circuit of Fig. 1 as an amplifying phase-selective detector, the switch S is thrown to the a.c. position, an auxiliary voltage $V_\sim$ (about 4 V), of the same frequency as the bridge voltage, being thereby applied to the bases of the transistors *via* the resistances r_1 and r_2. The arrows in Fig. 1 indicate the direction of the instantaneous currents flowing in various parts of the circuit during the half-cycle when the bases of the transistors are negatively biased with respect to their emitters; during the succeeding half-cycle, both transistors are non-conducting. Evidently, reversal of E with respect to $V_\sim$ will reverse the galvanometer deflexion; in other words, the circuit possesses the desired directional characteristics. By suitable choice of the values of r_1 and r_2, a voltage sensitivity of 15 mA/V (r.m.s.), with automatic protection from damage due to overload, is readily obtained.

ZERO ADJUSTMENTS

In both d.c. and a.c. measurements, preliminary zero adjustments are necessary in order to ensure that, when $E = 0$, the input current I and output current I_0 are also zero. Methods of zero adjustment analogous to those employed in thermionic valve circuits, e.g. variation of the ratio r_3/r_4, are inapplicable to transistor circuits. In contrast to the behaviour of thermionic valves, readjustments of resistances included in the output circuit of a transistor disturb the distribution of current and voltage in the input circuit; again, owing to the low input impedance of a transistor as compared with a thermionic valve, two independent zero adjustments are necessary in order to ensure that both the input current I and the output current I_0 are zero at the balance point. The method which was eventually adopted is shown in Fig. 2. With the switch S_1 in position 1, the control R_1 is adjusted until the galvanometer is undeflected. Switch S_1 is then thrown to position 2, and R_2 is adjusted until the galvanometer is again undeflected; finally, S_1 is thrown to position 3 in order to apply the unbalanced voltage E to the bases of the transistors.

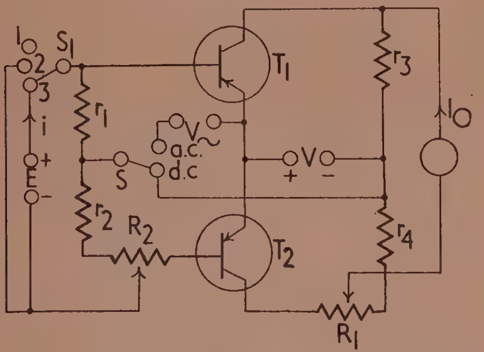


Fig. 2. Practical circuit diagram of detector

EXPERIMENTAL RESULTS

The characteristics of the amplifier are determined mainly by the quiescent values of the bias currents $i_3 = V/r_1$ and $i_4 = V/r_2$. The data in the table, obtained by using type OC71 junction transistors and a 100 Ω meter, with $V = 4\cdot5$ *V* and $r_3 = r_4 = 2000$ Ω, serve to indicate the manner in which the characteristics can be controlled by appropriate choice of the bias resistances r_1 and r_2. It will be noted tha the voltage sensitivity $S_v = \partial I_0/\partial E$ increases as the bia resistances are reduced; under similar conditions, the inpu resistance $R_i = \partial E/\partial I$ diminishes, but the current gai $S_i = \partial I_0/\partial I$ is not appreciably affected. S_v and R_i ar dependent, not only on the bias currents, but also upon th input voltage, approaching zero and infinity respectively whe E exceeds ±150 mV; the current gain, on the other hand, constant and independent of the input voltage throughout considerable range.

The limiting currents which flow in the input and outpu circuits under conditions of overload are governed by th quiescent values of the bias currents, and are only slightl affected by the magnitude of the overload voltage, provide that this exceeds ±150 mV. The input overload current approximately equal to the bias current of each transistor i the quiescent condition; thus if $r_1 = r_2 = r$, the maxima current accepted by the amplifier is approximately $I(max)$ V/r. The corresponding limiting output current, i.e. th current which the meter must be capable of carrying withou injury, is $I_0(max) = S_i I(max) = S_i V/r$. Thus if $V = 4\cdot5$ $r = 0\cdot5$ MΩ, and $S_i = 50$, the input and output overloa currents are approximately 9·0 and 450 μA respectivel The slight discrepancy between calculated values of $I(ma$ and $I_0(max)$ and the experimental values recorded in th table is due to the fact that, at zero base current, a curre of about 0·1 mA flows in the collector circuit of T_1; consequently, in order to reduce the collector current to zer and thus render the transistor T_1 non-conducting, the inpu current I must exceed the quiescent bias current b approximately 2 μA.

In conductimetric analysis, the a.c. source usually consist of a low power oscillator providing a bridge voltage of abou 4 V (r.m.s.) at a frequency of 800–1000 c/s. When a auxiliary voltage $V_\sim$ of this amplitude is applied to the base of the transistors *via* bias resistances of 0·15 MΩ, a voltag sensitivity of approximately 7·5 mA/V (r.m.s.) is obtaine The sensitivity of the a.c. detector may be further increase to a maximal value of about 15 mA/V by increasing th amplitude of the auxiliary e.m.f. or reducing the values of th bias resistances.

D.C. characteristics of detector

$r_1 = r_2 = r$		(MΩ)	0·15	0·25	0·5	∞
S_v	$E = 0$	(mA/V)	18	12·5	10	0·56
	$E = \pm 150\ mV$	(mA/V)	0·5	0·3	0·25	0·01
R_i	$E = 0$	(Ω)	2800	4000	5000	5400
	$E = \pm 150\ mV$	(MΩ)	0·1	0·17	0·2	3·0
$S_i = \partial I_0/\partial I$			50	50	50	30
$I(max)$		(μA)	32	20	11	1·3
$I_0(max)$		(mA)	1·6	1·0	0·55	0·04
Power consumption		(mW)	13	10	4·5	0·2

CONCLUSION

From the point of view of ensuring adequate protectio from overload it is desirable to operate the amplifier in th unbiased condition; the input and output overload current are then restricted to 1·3 and 40 μA respectively. Unfortunately, under these conditions, the voltage sensitivit falls to 0·56 mA/V, and the input resistance is of the orde of 54 000 Ω. Meters, such as the Baldwin centre-zero galvan meter, having pole-pieces so shaped that high current sensitivity is obtained only in the immediate vicinity of the nu point, are capable of carrying an overload current of at leas mA. For a balance detector intended for general use by experienced students, the author employs a meter of this pe in conjunction with an amplifier having bias resistances $0{\cdot}15\ \mathrm{M}\Omega$; the voltage sensitivity and input resistance are en approximately 18 mA/V, and $2800\ \Omega$ respectively, and e maximal current which the meter may be required to rry under conditions of severe overload is about 1·6 mA.

The lower limit of the current which may be detected is etermined by the zero stability of the amplifier. Whilst the ıbalanced e.m.f. produces equal and opposite changes cross r_3 and r_4, and thus causes a galvanometer deflexion, ıctuations in battery voltage or ambient temperature give se to approximately equal increases or decreases in the ırrents through these resistances; the effect of these disırbances on the meter is thus considerably reduced by the se of a balanced circuit. Drift due to variations in battery oltage is comparatively unimportant; using transistors lected at random, the deflexion produced by a change of 50% in battery voltage rarely exceeds that due to the oplication of $\pm 0{\cdot}5$ mV to the input terminals. Under ormal laboratory conditions, the mean rate of overall drift the output current due to the combined effect of battery ıd temperature fluctuations is about $0{\cdot}5\ \mu$A/h. Occasional ındom movements of the galvanometer pointer, due to regular fluctuations of approximately $\pm 0{\cdot}05\ \mu$A in the ıtput current, are superimposed on the slow unidirectional rift. The lower limit of the d.c. or a.c. current which may e detected with ease is about 10^{-9} A; if care is taken to eadjust the zero setting of the galvanometer during the course of each measurement, this lower limit may be reduced to approximately 5×10^{-10} A.

In a.c. measurements, incorrect readings are obtained when an angle of phase difference exists between E and $V_{\sim}$. Whilst an electrolytic solution normally behaves as a pure resistance when carrying alternating current, the electrolytic cell occasionally exhibits the properties of a resistance in parallel with capacitance, owing to polarization of the electrodes. In order to provide a means of eliminating this source of error in conductimetric analysis, the addition of a phase-shifting device, such as that described by Stuart,$^{(5)}$ may be found necessary or desirable.

ACKNOWLEDGEMENTS

The author is indebted to the Royal Society and the University of London for research grants.

REFERENCES

(1) Shea. *Principles of Transistor Circuits*, 3rd ed., p. 164 (New York: John Wiley and Sons Inc., 1954).
(2) Davidson. *Electronic Engng*, **26**, p. 548 (1954).
(3) Astbury. *J. Sci. Instrum.*, **17**, p. 25 (1940).
(4) Cosens. *Proc. Phys. Soc.* [*London*], **46**, p. 818 (1934).
(5) Stuart. *J. Sci. Instrum.*, **11**, p. 121 (1934).
(6) Walter. *Z. Tech. Phys.*, **13**, pp. 363, 436 (1932).
(7) Morton. *Trans Faraday Soc.*, **33**, p. 474 (1937).
(8) Harrison and Rowe. *Proc. Phys. Soc.* [*London*], **50**, p. 176 (1938).

Design for a sensitive self-recording gold-leaf electroscope

By P. Goodman, M.Sc., Division of Industrial Chemistry, Commonwealth Scientific and
Industrial Research Organization, Melbourne, Australia

[*Paper received* 11 *July*, 1955]

The principle of operation and construction of a gold-leaf electroscope, capable with calibration of measuring steady electron currents of the order 10^{-14} A is described. The output is in the form of voltage pulses, the frequency of which is proportional to current for low values, and logarithmically related for higher currents.

ı the course of electron diffraction studies the problem rose of measuring electron currents, i.e. intensities at a umber of points within the area of a pattern, and recording ıese simultaneously. One method investigated involved the se of the gold-leaf electroscope, which has high potential ensitivity and economic construction. The unit described ere was designed to be self-recording and compact ($0{\cdot}5\ \mathrm{cm}^2$ ı area).

In a standard gold-leaf electroscope, a leaf, which in its ero position hangs vertically, is subject to a horizontal eflecting field caused by a vertical earthed plate at a distance . By placing specific constant voltages on the electrode the ero reading may be shifted. The characteristics of this ıstrument are given in Fig. 1. The vertical scale of the urve in each case is determined by d and the electrode oltage. The most sensitive region is that between values of eflexion θ of 10° and 50°. The instrument becomes insensive when θ is nearly 90°, because, although the differential f the restoring force $mg \cos \theta$ becomes small, the deflecting field differential decreases more rapidly. By supplying a vertical component to the field in this region (θ nearly equals 90°) an unlimited sensitivity could be obtained. In practice, however, the limit is set by the elastic restoring couple at the bending point in the leaf. For θ greater than 90° the leaf becomes unstable. The characteristics for a modified electrode are given in Fig. 2.

After passing 90° deflexion the leaf will rise to touch the electrode m and discharge. The discharge pulse can be used under certain conditions as a signal to mark the end of the charging period of the leaf, and with a suitably arranged field the leaf can then be brought back to a zero position. This is the principle of the electrometer described below.

CONSTRUCTION AND OPERATION

The model used consisted of three electrodes as shown in Fig. 3. The electrode n was connected to a positive voltage source V_2 through a high resistance ($R \simeq 10^9\ \Omega$) and the condenser *C*. Electrode *l* was connected directly to voltage source V_1.

The charging process can be described in three stages.

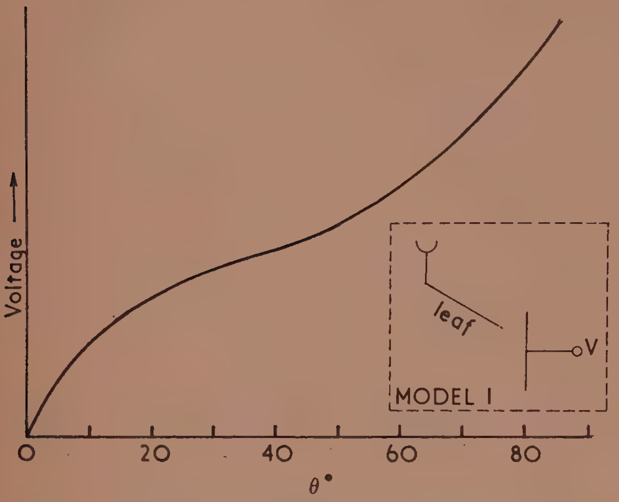


Fig. 1. Deflexion characteristics of the simple gold leaf electroscope (voltage scale arbitrary)

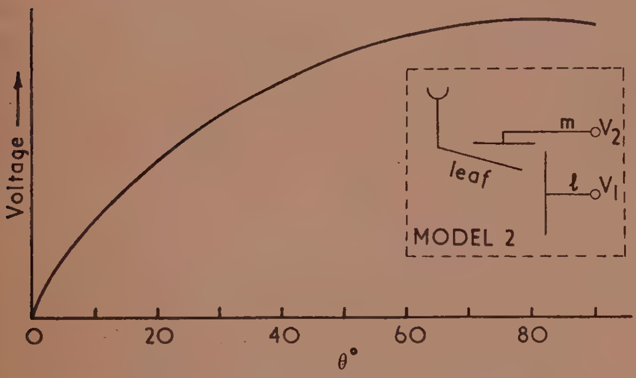


Fig. 2. Deflexion characteristics of the modified gold leaf electroscope (voltage scale arbitrary)

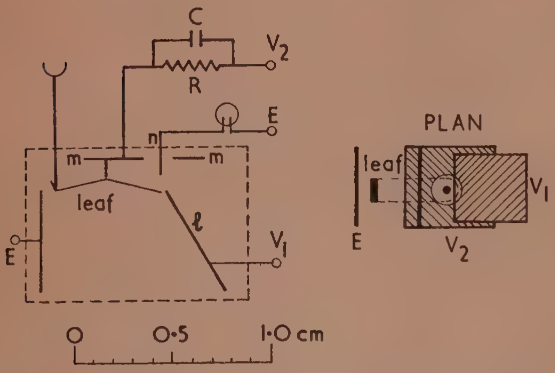


Fig. 3. Elevation with circuitry and plan of electroscope described. Plan and section of elevation enclosed by a broken line are to scale

(1) The discharged leaf has a stable horizontal position As it collects negative charge, the part of the leaf far fron electrode *n* moves towards the probe on electrode *m*. Afte a critical voltage rise (10–20 V) the leaf touches this prob and charges to $+V_2$.

(2) Being now positively charged the end of the leaf move swiftly to the probe *n* where it discharges the 20 pF condense *C* through the neon tube, and, with electrode *m*, is returne to earth potential.

(3) The leaf, being now in a reversed field, falls back t its equilibrium position, and the charging cycle begins again while electrode *m* charges up to its former potential +V at a rate governed by the time constant of the *RC* circuit A bias voltage $= V_1 - V_2$ of 130 V was used on electrode to make the resetting of the leaf effective.

Provided the decay time of the *RC* circuit is less than th time taken for the leaf to charge to the critical voltage, th time taken for stage (1) will be proportional to the current and the time for stages (2) and (3) will be negligible. As th current is increased the position is reached where the lea reaches the critical voltage while electrode *m* is below $+V_2$ and for a range of currents the period changes onl logarithmically with current. Thus it is possible to measur a current range of 1000 : 1 by recording time intervals wit an approximate range of 50 : 1, from the neon lamp. Th time constant may be varied a certain amount (to vary th measuring range), but if it is made too small (of the orde of $\frac{1}{10}$ s) the electroscope goes into oscillation after a reading

The main dimensions are shown by the diagram (Fig. 3) where the portion enclosed by a dotted line is drawn to scale The leaf used was 5 mm in length and 1 mm broad.

DISCUSSION

When the instrument was set up with the voltage $V_1 = 730$ V, $V_2 = 600$ V, $R = 10^9\ \Omega$, $C = 20$ pF, it wa found that with a current from an ionization cell of 10^{-13} A the output pulses were about 15 s apart, corresponding t a collector capacitance of approximately 0·2 pF. Thi calibration was carried out in dry conditions. In a humi atmosphere the performance deteriorated rapidly. To obtai consistent results it was therefore necessary to enclose an dehydrate or evacuate the system.

The principle may be applicable to small current measurin problems where automatic recording is desired, or wher cheapness and simplicity of construction are of concern The readings may be recorded permanently on a photographi film, or read from a mechanical register. Over most of th range of operation, a large number of readings can b obtained in a reasonable recording time (say a minute) s that the statistics of measurement are improved. In thes directions it has advantages over the string electromete which has generally replaced the gold-leaf electroscope fo most purposes. However, it is inferior to the electrometer i that it is less robust, and is sensitive to atmospheric conditions

ACKNOWLEDGEMENTS

The author wishes to thank Dr. J. M. Cowley for hi continual assistance during the course of the work and fo his advice in the preparation of the paper.

Experiments on the dependence of sensitivity on velocity profile in electromagnetic flowmeters

By J. A. Shercliff, M.A., Ph.D., Department of Engineering, University of Cambridge

[*Paper received* 10 *May*, 1955]

Mercury was passed along a non-conducting circular tube bearing flowmeter-type electrodes situated in a transverse magnetic field downstream of a small offset orifice. When the flow was concentrated near the electrodes the ratio of induced potential difference to the product of magnetic field and flow rate was found to reach more than twice the value appropriate to axially symmetric velocity profiles. When the flow was concentrated at the side of the tube this ratio could fall to zero and even change sign. Further downstream a steady state was reached, sometimes in an oscillatory manner.

In an earlier communication⁽¹⁾ it was shown theoretically that the form of the velocity profile in an electromagnetic flowmeter of circular section has a large effect on the sensitivity $S = U_{AB}/2\mu Hav_0$, where H is the intensity of the uniform transverse magnetic field, U_{AB} is the potential difference between two electrodes A and B situated at the ends of a diameter of the tube perpendicular to the field, and μ, the permeability of the fluid, is unity. The tube is non-conducting and has an inner radius a, and v_0 is the mean velocity of the fluid.

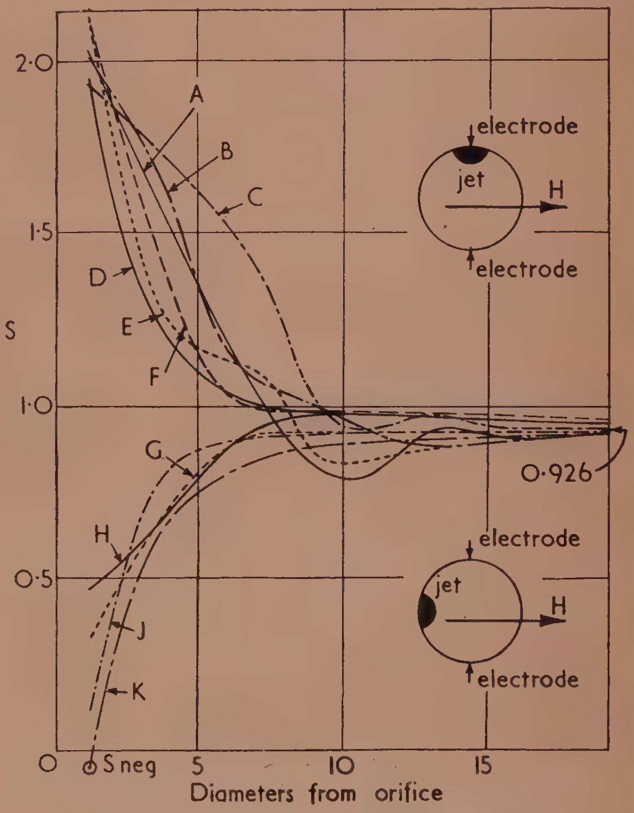
It was shown that S could be very large if the flow is concentrated near an electrode, that S approaches 0·50 if the flow is concentrated near the side walls, and that S could be less than 0·5 or even negative if reversed flow occurs near an electrode. Kolin⁽²⁾ showed that $S = 1{\cdot}0$ when the velocity profile is axially symmetric, and the author⁽³⁾ showed that S approaches 0·926 when the profile is distorted by magneto-hydrodynamic forces in laminar flow.

Experiments have now been carried out to demonstrate the dependence of S on the velocity profile. Mercury was passed along a plastic tube of 0·5 in. internal diameter lying entirely between the poles of a large electromagnet. The velocity profile was deliberately deformed by causing the mercury to enter the tube through a plug with a semi-circular peripheral orifice of 0·08 in. radius. Seven pairs of flowmeter-type electrodes at 1·5 in. pitch were installed downstream of the plug, the first pair being 0·6 in. from the flat face of the plug. The issuing jet of mercury could either be close to the electrodes or close to the side walls as shown in the figure. The rate of flow was indicated by another flowmeter which had been calibrated empirically. This meter had a narrow rectangular cross-section of aspect ratio 27 and was found to be quite insensitive to upstream conditions. The intensity of the magnetic field was found with a search coil and ballistic galvanometer. Potentials were measured with a potentiometer.

Typical results are presented in the figure, in which S is plotted against the number of diameters downstream of the face of the plug. The field intensity is recorded in terms of $M = \mu Ha(\sigma/\eta)^{\frac{1}{2}}$, and the flow rate in terms of $R = \rho v_0 a/\eta$. σ, η and ρ are the electrical conductivity, viscosity and density of the mercury respectively. Mean potential differences were recorded because the flow was eddying violently, although the total flow rate was always constant.

As was expected, S was as large as 2·0 initially when the jet was near the electrodes, and was approximately 0·5 when $M = 58$ and $R = 3850$ and the jet was at the side. In this case, however, at the higher values of M, S was initially still smaller and became negative when $M = 156$ and $R = 3920$, suggesting that there was reversed flow near the electrodes. S increased again when $M = 239$.

Further downstream in every case S approached 0·926, the theoretical value for steady laminar flow at high values of M. The critical Reynolds number in circular tubes is probably greater than 7800 when $M \geqslant 58$. In some cases S overshot the value 0·926 before approaching it, and sometimes showed an oscillatory tendency. It is suggested that



Variation of sensitivity downstream of orifice

Jet near electrodes:

curve A, $M = 239$, $R = 7800$; curve B, $M = 156$, $R = 4080$;
curve C, $M = 239$, $R = 3920$; curve D, $M = 58$, $R = 3950$;
curve E, $M = 102$, $R = 3950$; curve F, $M = 58$, $R = 7750$.

Jet at side:

curve G, $M = 102$, $R = 7800$; curve H, $M = 58$, $R = 3850$;
curve J, $M = 239$, $R = 3890$; curve K, $M = 156$, $R = 3920$.

the jet wanders about the cross-section before it disappears. There was no obvious simple trend as M or R increased. One would expect the settling length to increase as R increased or M decreased, but when the jet was near the electrodes the larger values of M appear to be associated with larger settling lengths. The spread of jets in a transverse magnetic field is obviously a novel and complicated phenomenon.

A disturbed velocity profile of the type studied could occur downstream of a half-open cock, etc. In the experiments it was found that even after nineteen diameters all situated in the magnetic field, S ranged from 0·895 to 0·96. The velocity profile would be expected to take still longer to approach a steady state if the fluid was a poor conductor or if the settling length was not in the magnetic field. It is evident that care is necessary in the situation of flowmete of circular section.

ACKNOWLEDGEMENTS

The experiments were conducted with facilities provided Cambridge University by the Atomic Energy Researc Establishment, Harwell.

REFERENCES

(1) Shercliff, J. A. *J. Appl. Phys.*, **25**, p. 817 (1954).
(2) Kolin, A. *Rev. Sci. Instrum.*, **16**, p. 109 (1945).
(3) Shercliff, J. A. Atomic Energy Research Establishme (Harwell), *Report No. X/R*.1052 (1953).

A simple electronic Fourier synthesizer

By H. B. Mohanti, M.Sc., A.Inst.P.,* and A. D. Booth, D.Sc., Ph.D., F.Inst.P., Birkbeck College Research Laboratory, University of London

[*Paper first received* 3 *June, and in final form* 30 *June*, 1955]

An attempt has been made to reduce the complexity of machines for two-dimensional Fourier synthesis by storing the accurately phased sine and cosine functions which are required on a magnetic drum. A small experimental model shows that the system is practicable and suggests improvements which might be incorporated into a complete machine.

This paper describes an attempt to use a magnetic drum store$^{(1,2)}$ for the presentation of Fourier synthesis contour maps, in the (x, y) plane, of the function:

$$\rho(x, y) = \sum_h \sum_k A(h, k) \begin{Bmatrix} \sin \\ \cos \end{Bmatrix} \left[2\pi \left(h\frac{x}{a} + k\frac{y}{b} \right) \alpha_{nk} \right]$$

The actual computation is performed by purely analogue means, so that the magnetic drum surface has to store not discrete binary digits but a continuous function of position.

It is not necessary, here, to describe how modern magnetic recording techniques for sound reproduction have resulted in systems which have a high degree of fidelity for the storage of sine waves. Suffice it to say that, with minor precautions, accuracies of ±5% in amplitude and phase can be attained and, by careful attention to detail ±1% is attained in available sound equipment.$^{(3)}$

These considerations, together with previous favourable experience of magnetic drum storage systems, suggested that it might be worth investigating the possibility of using a magnetic drum as a direct generator of the trigonometrical functions required for a Pepinski-type machine.$^{(4)}$

The circuits used in the investigation are, for the most part, standard and will not be described in detail here. Readers interested in the details may refer to the thesis which forms the basis of this note.$^{(5)}$

The general principle of operation is shown in Fig. 1. A storage drum A has a number of tracks: H_1, H_2, H_3, H_4, H_t.

The timing track, H_t, has recorded on its surface a set equally spaced markers which serve to divide up the rotatio period of the drum. These markers are amplified an

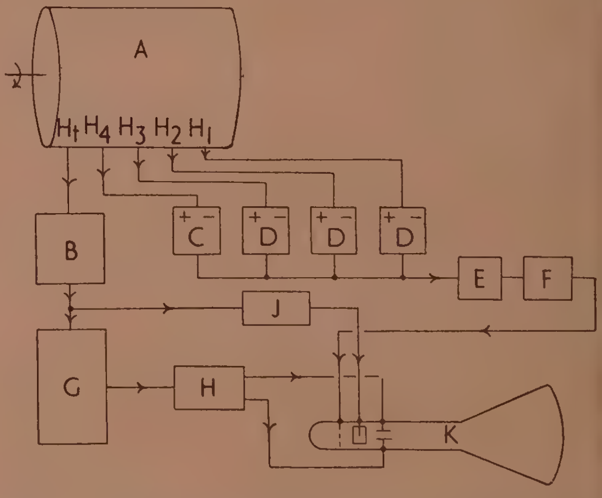


Fig. 1. Schematic diagram of two-dimensional Fourier synthesizer

A, storage drum; *B*, amplifier and pulse shaper; *C*, switch and amplitude; *D*, amplitude cont.; *E*, linear amplifier; *F*, contour pips; *G*, binary counter and adding circuit; *H*, paraphase amplifier; *J*, X-scan generator; *K*, cathode-ray tube.

---

* Now at Indian Institute of Technology, Kharagpur.

tandardized in the circuits shown and are then applied to wo circuits:

(i) a counter divider and adding circuit, *G*, and
(ii) an X-time base generator, *J*.

he X-time base generator simply causes the beam of a athode-ray tube *K* to be deflected, with uniform velocity, cross the tube face at each timing marker. The time of can is so chosen that it occupies all but a small fraction of he interval between markers.

The counter-divider and adding circuit is so designed that, fter each timing marker, the beam is deflected downward y a fixed interval. When all of the timing markers have een received during any given revolution, the counter contents eturn to zero and the process starts all over again. Means re provided for ensuring that the counter and drum position re always synchronized as soon as the drum has attained ts operating speed after switching on.

On the remaining tracks of the drum are stored signals vhich represent the various Fourier terms. These signals are ecorded on the drum surface by means of a set of standard ears having ratios 1 : 1, 2 : 1, 3 : 1, 4 : 1, etc. The source f sinusoidal recording voltage is conveniently taken to be sine-wave potentiometer of the usual type and this is onnected directly to the drum axis *via* the gearbox. Two xperimental points are worthy of mention: first that, to nsure linear recording, it is necessary to apply the usual “supersonic” bias current to the head during recording. In he present instance, since the drum-potentiometer system is otated by hand during the recording process, a suitable “supersonic” bias can be obtained from the 50 c/s mains and step-down transformer. The second experimental detail oncerns the phase-shift which occurs between recording and lay-back. Since it is the latter signals which have to be in orrect phase with each other it is necessary to introduce a hase lag on recording. The drum system operates with an ir gap between head and medium so that it is not easily ossible to determine the required lag theoretically; to overome this difficulty, signals of each required frequency were ecorded starting at the same initial position and the play-ack phase advances were measured by means of an oscillocope.

The operation of the pick-up circuits is such that the output ignal from any head is of the order of 1 mV, but has the dvantage of the extremely low impedance of $\frac{1}{10}\,\Omega$. This ow impedance means that the outputs from the various eads can be combined by series connexion *via* potentioneters to give amplitude variation, and *via* changeover witches to give positive or negative phase. This is shown n Fig. 2.

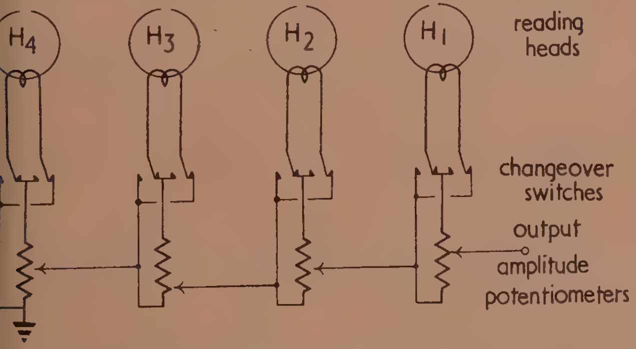


Fig. 2. Phase and amplitude control with summing circuit

Only after addition is the output voltage amplified, so that only one amplifier is required. The final stage consists in the application of the amplified sum voltage to a set of comparator circuits which emit sharp pulses when the input voltage crosses various pre-set levels. These pulses are used to brighten up the oscilloscope trace and thus to produce contours in the usual manner.

To show how a device of this type can produce the required pattern, Fig. 3 shows a simplified diagram of the recorded patterns which would be used to generate the necessary waveforms for the Fourier term:

$$\sin 2\pi\left(\frac{x}{a}+\frac{2y}{b}\right)$$

In Fig. 3(*a*) is shown the recorded contents of the timing, or clock track, which for this simple example is assumed to contain eight markers. Fig. 3(*b*) shows the recorded sine waves which are required to give the desired outputs. It will be noticed that since the *x* frequency is unity, each clock interval contains one complete period of the sine wave; and that, since the *y* frequency is two, the complete set of eight clock intervals contains two complete periods of repetition. It may also be seen that, at the end of each clock interval a small gap is left in the recording to allow for fly-back of the cathode-ray tube beam.

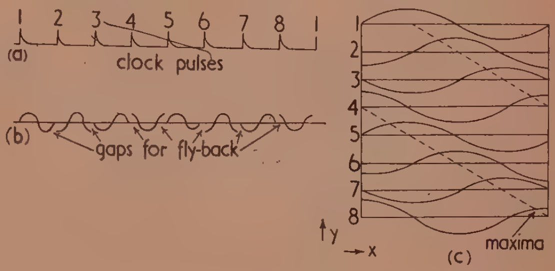


Fig. 3. Generation of sin $2\pi\left(\frac{x}{a}+2\frac{y}{b}\right)$

The result of these operations is shown in Fig. 3(*c*) and it will be seen that if the output voltage is applied to modulate the beam a set of standard Bragg–Huggins(6) fringes will be produced. Actually, of course, the contour generating circuits reduce the pattern to a series of straight lines parallel to the lines of maxima which are shown in the figures.

To test the validity of the principles which have just been described, use was made of a number of pieces of equipment which happened to be available in the laboratory. The first of these was the original magnetic storage drum(1) to be used in this laboratory and was, so far as can be discovered, the first storage unit of this type to be operated successfully anywhere. The unit is 2 in. in diameter and 12 in. long, it has twenty-one tracks and is plated with a 0·001 in. coating of nickel.

For the purposes of the experiment only five of the tracks were used; one for the clock, which contained sixty-four equi-spaced markers, and four for the terms:

$$(1, 0, 0), \quad (2, 0, 0), \quad (1, 3, 0), \quad (1, 2, 0).$$

The amplifiers used were some which had been built for digital computer work.

For the oscilloscope, use was made of a type 73 triggered sweep test unit with a 3 in. tube, and the auxiliary circuits were mounted on a small aluminium panel. The total number of valves in the unit was fourteen, and the power consumption 300 W.

Fig. 4 shows photographs of the outputs which were obtained for various combinations of the available waveforms. The photographs in Fig. 4 were obtained using an ordinary half-plate studio camera with an *f*/11 lens. Under these conditions an exposure of some minutes was required and various random fluctuations in the brightness of the trace have led to a great deterioration in quality. Not all of the bad definition is, however, due to the photograph; one of the most serious causes of variation has been shown to be due to precession of the drum on its bearings, and any attempt to construct a large and practically useful model of the machine would have to overcome this defect. Measurements of precessional eccentricity on the drum which was used show this to be of the order of ±0·001 in. which is largely due to wear of the bearing system during the five years during which the unit was in use for its original purpose. More recent drums, such as that used in A.P.E.(X).C.,(7) have eccentricities which are held to ±0·0001 in. and it is considered that this precision would be adequate for most purposes. If, however, a still more accurate representation were required, use could be made of Bernoulli effect heads which can follow variations in drum surface position a adequate speeds. The principle of operation of a recordin head of the Bernoulli type is shown in Fig. 5.

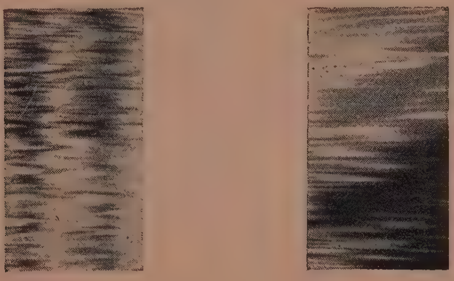

(*a*) (*b*)

Fig. 4. Photographs of machine output for typical configurations

(*a*) Output for plane (2, 0, 0).
(*b*) Combination of (1, 0, 0) or (1, 3, 0).

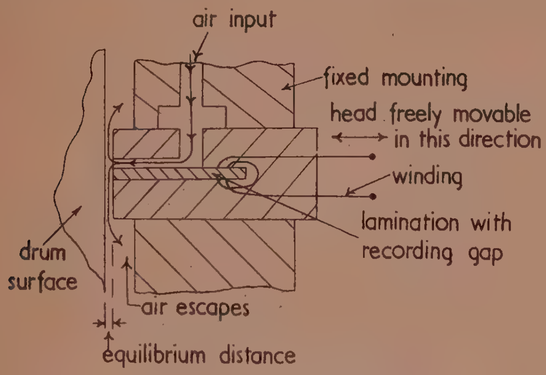


Fig. 5. Bernoulli effect head

When air is blown through a small orifice in a disk whic is in close proximity to a flat surface, contrary to expectatio the disk is first attracted towards the surface, and then, whe a certain fixed distance of approach is reached, takes up a equilibrium position.(8) The system will thus follow movements of any surface to which it is approximated and physical embodiment of the device, devised and constructe by Hagen,(9) will follow variations in surface position of u to 0·005 in.

A final point in connexion with the drum system concern the introduction of phases other than 0° and 180°; it extremely simple to arrange that the heads can be advance or retarded, peripherally along the drum surface and, i this way, general phase angles can be introduced. A development of this type would fit in rather well with Bernoulli effec heads, since no great precision would then be required in th head-to-drum positioning of the adjustment.

Finally it may be of interest to mention the probable siz and characteristics of a fully engineered version of the abov machine. The storage drum could conveniently be th 256-head unit which is used on A.P.E.(X).C., or, if mor than 256 terms are required, several such units. These ar 8 in. long by 5 in. in diameter and a $\frac{1}{6}$ h.p. motor will driv up to six at 3000 rev/min. The phase and amplitude contro consist, for the centro-symmetric unit, of a small potentic meter and a changeover switch, 256 such controls could b accommodated on a panel 17 × 17 in. The oscilloscope an circuits would involve some thirty to forty valves dependin upon the number of contours which are required. Th number of lines in the *y* direction would be in this case 51 which would give a definition roughly equal to that obtaine in the British Television service.

REFERENCES

(1) BOOTH, A. D. *Electronic Engng*, **21**, p. 234 (1949).

(2) BOOTH, A. D., and BOOTH, K. H. V. *Automatic Digit Calculators*, p. 115 (London: Butterworths Scientifi Publications, 1953).

(3) BEGUN, S. J. *Magnetic Recording* (New York: Murra Hill Books, 1949).

(4) PEPINSKI, R. (Ed.). *Computing Methods and the Phas Problem*, p. 167 (Pennsylvania: State University o Pennsylvania, 1952).

(5) MOHANTI, H. B. *The Design and Construction of a Electronic Fourier Synthesis Machine*. M.Sc. Thesis University of London (1953).

(6) BOOTH, A. D. *Fourier Technique in X-ray Organi Structure Analysis*, p. 96 (London: Cambridge Un versity Press, 1948).

(7) BOOTH, A. D. *Math. Tables Aids Comput.*, **8**, p. 9 (1954).

(8) EDSER, E. *General Physics*, p. 406 (London: Macmilla and Co. Ltd., 1929).

(9) HAGEN, G. E. *Computers and Automation*, **2**, p. 23 (1953

Laboratory and workshop notes

A permanent vacuum seal

By the late E. Schwarz, F.Inst.P., Hilger and Watts Ltd.,
London, N.W.1

[*Note received* 3 *February*, 1955]

connexion with the work on vacuum thermopiles(1) the oblem arose to fix windows of special materials to glass or etal containers and to guarantee a vacuum of the order of $^{-3}$ mm to 10^{-4} mm for an unlimited time after sealing off om the pumping system. The most suitable window aterial, transmitting in the infra-red region, is an alkali lide, especially potassium bromide. The main difficulties ising from the use of these substances is the high expansion efficient (of the order of 4×10^{-5}) compared with the low efficient of lead glass ($9{\cdot}5 \times 10^{-6}$) and the inferior strength the alkali halides.

A sufficient degassing of the glass container, i.e. the moval of the adsorbed layer of water and gas from the rface of the glass, requires at least a temperature of 150° C d preferably higher. Under these circumstances an alkali lide window cemented directly to the container invariably eaks, however slowly cooling takes place. After some eliminary experiments the following design was adopted.(2)

The window is supported on the periphery of an aperture the vessel in such a manner as to withstand the mechanical resses due to the difference of pressure and at the same time permit the window to expand and contract independently the vessel. The actual vacuum seal is effected by a foil yieldable metal cemented to the outside of the window d to the parts of the vessel immediately surrounding the indow. The foil should be thick enough to provide an fective vacuum seal and to withstand the stresses due to essure differences, but it should not be so thick as to nder the relative movement of the window and the vessel uring temperature changes. The best results are obtained ith foils of silver or aluminium depending on the cement ed, the foil being of the order of 0·001 in. thick.

A suitable cement should have low vapour pressure even elevated temperatures, good wetting qualities, chemical ertness and a softening temperature which is high enough withstand the operation of degassing under vacuum, but ot so high as to render the assembly of the parts impossible. cement which fulfils all these conditions for all the window aterials in question is Araldite. Silver chloride can be used ith advantage for certain materials, the limitations to its neral use arising from its great chemical activity.

The construction of the seal in two forms is illustrated in e figures. Fig. 1 shows an axial section through a part a glass tube, with the window fixed to the end of the tube. ne glass tube (1) is thickened towards the end at (2) and a lindrical recess (3) is ground therein of a diameter to receive the window (4) with a small clearance and to such a depth that the outer face of the window is flush with the end of the glass tube. The bottom of the recess is ground smooth with fine emery powder in order to reduce the friction between it and the window when relative movement due to differential thermal expansion takes place. The sealing foil (5) is a flat ring, being cemented to the marginal part of the outer face of the window and to the end face of the glass tube.

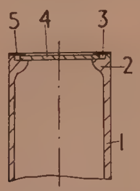


Fig. 1. Window fixed to the end of a cylindrical glass tube

Fig. 2(*a*) shows a rectangular window, fixed into the side of a cylindrical glass tube and Fig. 2(*b*) is a transverse section through it. The tube (6) has a portion ground away at the side to a plane surface parallel with the axis. The length of the recess so formed is slightly longer than the window and the width of the opening is approximately the width of the window. The rectangular smooth steel plate (7) is placed on the aperture and supports the window (8). The seal is completed by cementing on the assembly a rectangular piece of foil (9) to the window and the edges of the aperture.

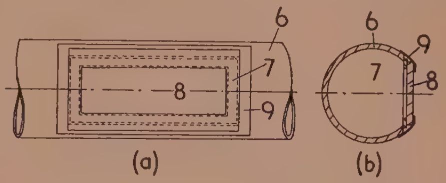


Fig. 2. Window fixed into the side of a cylindrical glass tube

It has been found that silver chloride, due to its chemical activity, cannot be used when the window material consists of an alkali halide. In that case Araldite has to be used as a cement and although it has been stated(3) that the vapour pressure at room temperature is as low as 2×10^{-7} mm, a slow deterioration of the vacuum has been observed. This fact necessitates the use of a suitable getter to restore the vacuum after some months to its full value. It has been found that regettering for the first time after approximately six months, with increasing intervals for the second and third regettering will suffice to keep the necessary vacuum for at least six years—the time of experience—and very likely for much longer. During the operation of regettering a fall of vacuum occurs initially, due to the liberation of absorbed gas from the getter, but as soon as more getter material evaporates the pressure decreases rapidly to the original value.

Windows of quartz and fluorite can be cemented with silver chloride if, in the case of fluorite a layer of silver is burned into the material where the seal is affected. Even lead glass shows signs of chemical attack by silver chloride at elevated temperatures and a satisfactory seal is only obtainable with a burned-in silver-layer. With these window materials and silver chloride cement the permissible degassing temperature is up to 350° C and the vapour pressure so low that no extra getter or regettering is required to keep a permanent vacuum of the order of 10^{-4} mm of mercury. Metal-to-glass seals(4) and seals of special windows to a container with the aid of a thin copper diaphragm(5) on continuously-evacuated systems have been described recently. These seals, using Araldite as cement, can be cooled down to low temperatures in cases where the window is not an alkali halide. With the seal described above, it was possible to cool down a sealed-off glass container with a window of potassium bromide to liquid air temperature in 30 min and after warming up, the pressure within was found unchanged.

This seal may be found useful in other vacuum apparatus, where the presence of traces of the cement or its components is not harmful.

The author desires to acknowledge the great help received from Mr. R. Elam and to thank Hilger and Watts Ltd., for permission to publish this note.

REFERENCES

(1) Schwarz, E. British Patent Specification 578.187 and 578.188 (1942–1946).
(2) Schwarz, E. British Patent Specification 652.702 (1948–1951); U.S.A. Specification 2.604.220 (1952); German Specification 818.383 (1949).
(3) Johnson, T. E. A.E.R.E. G/R 486 (January 1950).
(4) Quarrington, J. E. *J. Sci. Instrum.*, **31**, p. 387 (1954).
(5) Roberts, V. *J. Sci. Instrum.*, **31**, p. 226 (1954).

A mechanical seal for very high pressures

By D. Anson, Ph.D.,* Dominion Physical Laboratory, Lower Hutt, New Zealand

[*Note received* 23 *February*, 1955]

In designing equipment to operate at very high fluid pressures it is usually considered necessary to work to great precision in making sealing devices. The principle described here has been found completely satisfactory up to 15 000 atmospheres, with alcohol as the working fluid, the pressure being then limited by other factors in the apparatus. Use is made of the distortion of a relatively flimsy metal ring to provide a good enough seal to prevent extrusion of a rubber member forming the seal proper, using parts of only moderate accuracy.

Fig. 1 illustrates a form suitable for sealing a joint between two pipe flanges. Tightening of the joint distorts the metal ring as shown in Fig. 1(*b*), so that it seals on both of the edges *A* and *B*, which are initially sharp. The close fit at these edges, which are exposed to the fluid pressure through the rubber member, prevents extrusion of the latter even at very high pressures. The metal ring need not, initially, be a tight fit in its housing, neither is it necessary to pull the flanges up hard (in fact this tends to curl the edge *B*); as soon as a high pressure is applied, it will distort the metal ring to maintain close contact.

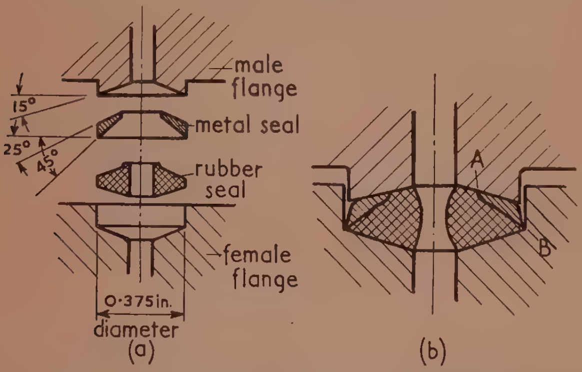


Fig. 1. Section through high pressure pipe seal
(*a*) Exploded view. (*b*) Assembled

A similar seal (Fig. 2) has worked well as a piston seal. In this form the entry to the cylinder has a slight lead, ar both the metal ring and the rubber seal are initially tigh The metal ring was made from a 50 ton U.T.S. steel, and th rubber used was 69% pure with a Shore hardness of A37–3 but these properties do not appear to be critical. In the sam application difficulty was experienced with piston seals c the types described by Bridgman(1) and Poulter,(2) possib because the manufacturing tolerances applied to the apparatu were incorrect, or the rubber was of the wrong grade.

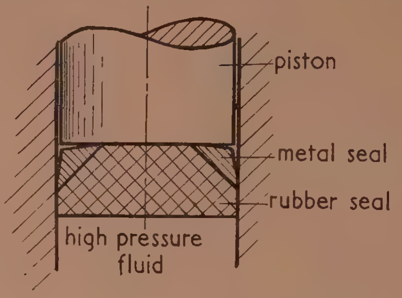


Fig. 2. High pressure piston seal

A further feature of the present design is the ease with whic the steel rings may be removed by screwing a suitable bo into the centre hole. The rings are regarded as expendable.

This note is published by permission of the Secretar Department of Scientific and Industrial Research.

REFERENCES

(1) Bridgman, P. W. *The Physics of High Pressures* (Londo G. Bell and Sons Ltd., 1931.)
(2) Poulter, T. C. *Phys. Rev.*, **40**, p. 863 (1932).

Construction of a lead-screw without a master thread

By L. R. Baker, A.R.C.S., B.Sc.,* Imperial College of Science and Technology, London, S.W.7

[*Note first received* 5 *October*, 1953, *and in final form* 21 *February*, 1955]

The need was recently found for a lead-screw which woul permit the accurate positional control of an interferomete mirror anywhere over a total range of displacement c about 2 in., and it was felt that control to within distances c the order of a wavelength of light could only be attained b the use of a finely pitched screw. Fine lead-screws c 1000 turns/in. or more can be cut on a precision lath Using a diamond tool a helical groove is ruled on a accurately cylindrical screw blank,(1) and although by th subsequent use of a Merton(2) nut the more rapid periodi errors can be eliminated in the final thread, the slow cumulative errors associated with the master screw could still b transmitted.

An alternative method(3) of making a lead-screw has bee investigated which need not depend in any way upon separate master screw. The thread of the screw is formed b cementing a closely-wound layer of wire to the surface of cylinder. A variety of profiles can be obtained by usin more than one layer of different diameter wires, or by usin multi-start threads. Screws down to 2000 turns/in. have bee made so far by this method.

A conventional type of wire-winding apparatus can b sed for wires down to 0·005 in. diameter, that is for making crews of up to 200 turns/in., but if a screw of still finer itch is required, the presence of specks of dust and vibrations ead to difficulties in obtaining a closely-packed layer of wire xtending over a few inches. The method to be described as been used successfully for all the wires tried so far, the mallest of which was 0·0005 in. diameter.

---

* Now at Shell Research Ltd., Thornton, Cheshire.

* Now at Royal Aircraft Establishment, Farnborough.

The wire must be wound with the utmost precision and egularity on the screw blank, and a device (termed the ‘follower-nut”) shown schematically in Fig. 1 was developed or this purpose. During the course of winding a clean lexible surface presses down on to the wire, and packs the urns closely together excluding dust and dirt.

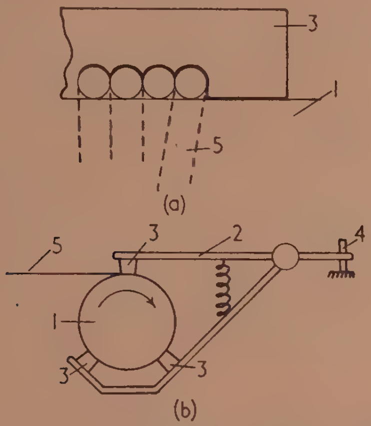


Fig. 1. (*a*) An enlarged section through the follower-nut parallel to the screw axis. (*b*) A section through the follower-nut perpendicular to the screw axis

The screw blank (1) was made to rotate between centres, nd a number of turns were put on as evenly as possible vithout the aid of the follower-nut (2). This nut, comprising hree elements of dried elder pith (3), such as is used by vatchmakers for cleaning bearings, was clamped over these urns so that less than half its width was sliding over the are cylinder in the path of the oncoming wire. As the ylinder was rotated the follower-nut advanced with the vire at a rate corresponding to the average pitch of the first oughly-wound turns. A ball race (4) moving along a flat urface prevented the nut from rotating. The slight negative ead (5) of the wire, and the absence of dirt due to the excellent leaning action of the pith, soon served to reduce the advance f the nut to its smallest value, namely that obtaining at the osition of stability where all the turns are touching and egularly wound. No external lead-screw is required and the rocess is completely automatic once it has been started.

Such a simple lead-screw when used with a Merton nut is urprisingly effective if the power to be transmitted is very ow. It has been found, however, that a much better grip etween the nut and the screw could be obtained by winding n another layer of wire of half the diameter of the base ayer so that it ran into the channel already prepared by the atter. This second layer can also be laid down by the ollower-nut, the advance of which will be accurately governed y the base layer.

Although this technique is quite straightforward attention o certain details should be given if screws of say 1000 turns/in. r more are required.

As a general rule all the apparatus, including bearings, hould be as clean and as dust free as possible. The moving arts should be quite free and of small inertia, so that the tension of the wire is always small and never changes suddenly. The speed of rotation of the screw when being wound depends on the thickness of the wire, but should not be much greater than 1 rev/s for wires of less than 0·001 in. diameter.

Owing to the effects of thermal expansion, the screw blank should be of the same material as the wire, though this is not absolutely necessary. Stainless steel would be a good choice, but brass has been used most often and is more readily available. The surface of the cylinder should be finely-turned, honed and polished so that no scratches are visible. All traces of the metal polish and any grease should be removed with clean acetone before the wire is wound on.

The wires should have a uniform cross-section and high tensile strength. Nichrome wire is readily available down to 0·0005 in. diameter and should be used bare rather than in the oxidized form. This type of wire has been used in a number of screws and is easy to handle, being both hard and strong.

One pith follower-nut was made from an adapted retort clamp, the strips of pith being stuck on to the jaws. The operating surface of the pith should be “dressed” so that it will conform to the curve of the screw blank. This is easily done by fixing a piece of fine emery cloth round the cylinder itself and then dressing the nut to this surface. It has also been found advisable to relieve the pith surface, and this can be done by pressing the nut on to a 10 turns/in. screw of about the same diameter as the blank and which has a sharp top and a straight flat-bottom profile. Finally, and just before clamping the nut over the first turns, a very thin skim should be taken from the working face of the pith by means of a sharp razor blade, so that a fresh clean surface is presented to the cylinder. A convenient pressure of the follower-nut on the screw is that which just produces an audible squeak as the clean screw is rotated. Pure oil, as used by watchmakers, should now be applied to the screw so that the nut advances in silence.

Screws have been made in which only the ends of the wire were fixed, and they all worked satisfactorily. Nevertheless, when continued operation was required with the finest wires, it was thought desirable to cement the wire along the whole of its length. If it is intended to do this, the two ends of the wire should be fixed with cork-lined metal clips. The oil necessary for the winding process could then be removed by thoroughly washing the whole screw in a suitable solvent. Of the various cleaning fluids tried, pure acetone proved to be by far the best. If necessary, acetone can be purified by crystallizing out one of its additional compounds which is subsequently decomposed to give pure acetone free of any dissolved solids. Acetone containing 1% of water as the only impurity is, however, obtainable commercially.

The adhesive should be thin and can be applied as a spray or with a fine camel hair brush. If the surfaces are clean, it will be drawn down on to the surface of the cylinder under the wires, so that when set, the upper profile of the thread is unaltered. Microscopical examination of the upper profile, and of the cylinder when the wire was intentionally stripped off showed this to be the case. The adhesive should be chemically and physically stable, and also have a high cohesive strength. Generally speaking, the resin type of adhesive is preferred for bonding metals. Cellulose esters have been used, but they tend to be dimensionally unstable with humidity changes. A highly successful adhesive in this respect is a dichromated solution of gelatin, which when baked is converted into a stable resin. Of the synthetic resins a thin Araldite mixture is extremely suitable, and will only soften by prolonged boiling in water. The hardening of the adhesive should not be hurried, and it is preferable if the screw can be left for about a week at room temperature followed by slow baking at an elevated temperature.

The standard type of Merton nut can be used when the screw rotates in one direction between fixed centres, so that the nut advances along it. It was hoped, however, that with the profile obtained by using two layers of wire, and with the absence of the periodic errors normally associated with a lathe-cut screw, a nut of a much harder material could be used, thus permitting the construction of the normal type of micrometer screw in which the nut is stationary and the screw can be rotated by hand in either direction.

Several nut lining materials were tried for smoothness of adjustment of the screw and apparent freedom from backlash, and the most satisfactory was found to be polytetrafluorethylene (P.T.F.E.). This material in the powdered form was cold-pressed into a sheet about $\frac{1}{16}$ in. thick at a pressure which was roughly estimated at 2–3 t/in^2. The pressure was such that the surface of the P.T.F.E. could still be scratched quite easily with a scriber, but was strong enough to resist crumbling in the hands. Two strips of this material were used to line the bottom vee of the nut. The screw was placed lightly in this vee and was kept in position by a member of pith which could be made to press down on to the top. As the screw was slowly rotated in one direction the top pith element caused it to advance over the two bottom elements of P.T.F.E., and in doing so gradually formed a mating thread in the latter. The screw was well lubricated and after a dozen or so turns the pressure on the pith element was increased so as to deepen the thread. This thread-forming process was continued until the screw was just beginning to bind and then the pressure was slightly released. At this point the process was complete, and the screw could be reversed in direction as required. Microscopical examination of the thread formed in the P.T.F.E. showed that it was about the same depth as that on the screw.

One micrometer screw made in this manner had 303 turns/in. The base layer was No. 44 s.w.g. enamel-covered copper wire, and the second layer was Nichrome wire of about half this diameter. The screw was about 2 in. long and $\frac{3}{8}$ in. in diameter, and the nut was 1 in. long. The linearity of the screw was tested by plotting its advance against a dial gauge reading. The screw was tested over the full range of the dial gauge which was $\frac{1}{4}$ in., and Fig. 2 shows a portion of this curve. The gradient or advance of the screw per turn was 0·00343 ± 0·00003 in. and the departure from linearity amounted to 0·0001 in. It seems probable that the limiting factor in the linearity of the lead is to be found in the dia gauge itself, and in the coupling between this and the screw The diameter of the base layer of wire was found by mean of a micrometer to be 0·0032 ± 0·0001 in. which differ significantly from the pitch by something less than 0·0001 in The measured backlash of this particular screw was about 2% of a turn, but depended on the tightness of the nut.

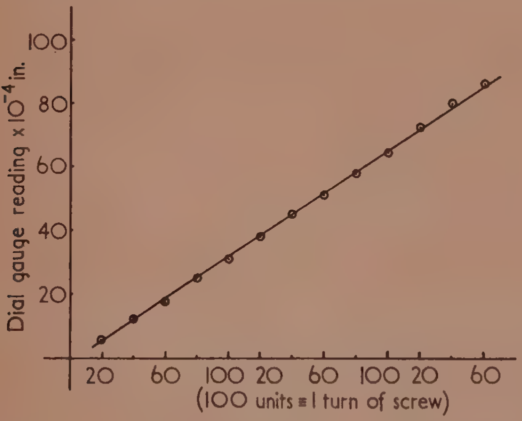


Fig. 2. Graph indicating linearity of the lead-screw

Factors which would govern the performance of this typ of screw are small variations of the wire diameter, and th degree of packing of the base layer. The effect of both o these factors is minimized, however, by the technique o winding described above, and is only really apparent whe we compare the pitch of the screw with the diameter of th base wire. Commercial wire has been used in these experi ments, and no attempt has been made so far to select wir of a particularly uniform cross-section. Encouraging result have been obtained by the use of the nut described above but more work will be carried out with a view to reducin the backlash. Since wires have been produced down to 3 μ in diameter by drawing and electrolytic polishing,$^{(4)}$ a screw of 10 000 turns/in. should not be impossible. Thus the valu of the method for producing diffraction gratings by th replica technique$^{(5)}$ is immediately apparent. A wide rang of thread profiles could be produced by the use of a multi start base layer and building on this with wires of a differen diameter. The method offers the possibility of obtaining constant groove form which does not depend on the accurac of the cylindrical or part spherical blank, but only on th use of wires of a uniform circular cross-section.

The author wishes to thank the Department of Scientifi and Industrial Research for the provision of a maintenanc grant held when this work was carried out.

REFERENCES

(1) Hall, R. G. N., and Sayce, L. A. *Proc. Roy. Soc. A* **215**, p. 536 (1952).
(2) Merton, Sir T. *Proc. Roy. Soc. A*, **201**, p. 187 (1950).
(3) Baker, L. R. British Patent Application No. 16106/54.
(4) Bockris, J. O'M., and Parsons, D. F. *J. Sci. Instrum* **30**, p. 340 (1953).
(5) Dew, G. D., and Sayce, L. A. *Proc. Roy. Soc. A*, **207** p. 278 (1951).

The temperature control of a fluid stream

By R. S. Barnes, B.Sc., Atomic Energy Research
Establishment, Harwell, Berks.

[*Note received* 7 *February*, 1955]

It is often necessary to control accurately the temperature o a stream of fluid which is flowing relatively fast. To do thi it is essential to have a control system with a very rapi response to changes in the supply voltage, ambient conditions and the rate of fluid flow. By combining the thermomete and heater, very rapid response to changes of voltage an ambient conditions was attained in the temperature-controlle laboratory furnace already described* and it has been foun possible to use the same simple system and circuit to contro the temperature of a fluid stream.

The heater consists of two series resistors forming two arm of a Wheatstone bridge, one of nickel/chromium and the othe of platinum (R_2 and R_1 respectively in Fig. 2 of previou paper*). This heater is placed in the fluid stream in goo hermal contact with the fluid; the nickel/chromium resistor eing positioned so that the fluid flows past it first. Should he fluid be such that it attacks the nickel/chromium of the eater this part of the winding can be kept from contact with he fluid by winding it on to the outside of the tube carrying he fluid. Should, however, the platinum be attacked by the luid, then it will be necessary to replace it by some other onductor with a high temperature coefficient.

---

* Barnes, R. S. *J. Sci. Instrum.*, **28**, p. 89 (1951). [The valu of R_6 in Fig. 2 should read 300 kΩ, and not 300 Ω as printed.]

In designing the heater it is important that the thermal ontact between fluid and heater should be sufficient for the luid almost to attain the temperature of the platinum resistor, vhich is the *thermometer* of the system, as it is this tempera-ure which is actually controlled by the electronic control ystem. As the temperature of the platinum wire oscillates etween two fixed values imposed by the controller, it is mportant that the time the fluid is in contact with the heater hould be greater than the switching period of the system. short switching period, which will be essential at high speeds f flow, can be obtained by using very thin platinum wire, rranged as a coiled coil if necessary.

The above arrangement has been employed satisfactorily to eat an air stream flowing with speeds up to 100 cm/s, when he switching period of the controller was less than 0·2 s. emperature control to better than ±1° C was attained at emperatures up to 400° C.

Reduction of scatter in monochromators

By K. W. Keohane, B.Sc., and W. K. Metcalf, M.B., B.S., Department of Anatomy, University of Bristol

[*Note received 7 March*, 1955]

rroneous values for molecular extinction obtained by pectrophotometry can often be attributed to lack of spectral urity from single monochromators. Figures given in the terature for the percentage impurity from a monochromator epend so much on the particular instrument and detector sed that they are of little significance to an individual vorker.(1) Frequently the intensity of the unwanted or cattered radiation is quite independent of wavelength and, t or near an intense absorption band, it may well be a large action of the total transmission.(2) If, in addition, the specific bsorption of a specimen coincides with a wavelength at hich the output from the source or the sensitivity of the etector is low, the error becomes of even greater importance.(3)

Such conditions can exist when measurements are made of e Soret band of oxyhaemoglobin, as the absorption maxi-num is in the extreme violet and coincides with a region of ery low emission from a tungsten lamp. Using a micro-pectrophotometer,(4) which incorporated a Littrow type, ouble transmission, quartz monochromator (see Fig. 1), a alue of 4175 Å was obtained for the Soret maximum. By ducing spectral impurity with a filter, it was found that the osorption maximum shifted to 4150 Å, a value also obtained Sidwell and others.(5) This displacement of the absorption aximum was clearly due to the presence of parasitic light.

Various methods for improvement of the spectral purity of e light from monochromators have been suggested but enerally a major change in the design of the instrument has en required. Conditions imposed by the remainder of our pparatus did not permit the introduction of a sector disk has been suggested by Walsh.(6) A short study of the urce of stray radiation has been made in our particular monochromator. As a consequence, sufficient improvement has been obtained for the wavelength of the Soret maximum to remain unaffected in position by the addition of a filter.

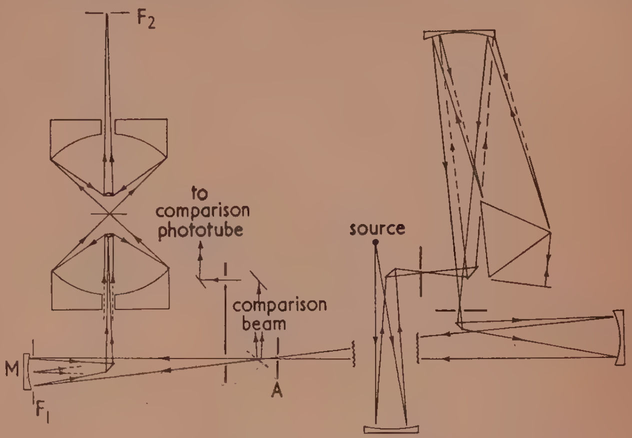


Fig. 1. Optical diagram of microspectrophotometer incorporating reflecting microscope

F_1, field stop (sub-stage); F_2, field stop (image plane); A, aperture stop (imaged out by mirror m).

Whilst complete spectral purity has not been achieved, the following hints may be of use to others who are faced with the same problem.

Origin of scatter

(i) From sleeks, scratches, and dust on reflecting surfaces.

(ii) From the prisms faces. As 5% reflexion occurs at all glass–air interfaces, care should be taken to ensure that this reflected light is completely absorbed and does not re-enter the system. Errors in the figure of these surfaces and dust on them will also increase scatter.

(iii) From internal reflexions within the prism.

(iv) From obstructions to the dispersed beam, e.g. prism supports.

(v) From reflexions of the dispersed beam by the back of the slits.

(vi) From scatter at the slits due to dirt, wrong design, or inexact focusing.

(vii) From overfeeding the aperture of the monochromator.

Most of the above factors were found to be contributory to the scatter in our particular instrument. They were detected by feeding the monochromator at its correct aperture from a carefully screened source and examining the light path in the dark. In a dust-free atmosphere, light could only be seen at positions where scatter occurred. Having carefully re-aluminized all reflecting surfaces, it was observed that factors (iii), (iv) and (v) constituted the most serious remaining sources of scatter.

Considerable scatter occurred at the base and ends of the prism which had been left fine ground in the course of manufacture (Fig. 2). In order to absorb the light incident on these surfaces, it was necessary to coat them with a highly absorbing material of the same refractive index as that of the prism. These requirements are most nearly met by Swedish pitch.(7) A small quantity was dissolved in benzene and painted on the ground surface to ensure complete contact of the pitch with the quartz. This was repeated until a thick black coating had been built up. When the prism was replaced in the monochromator it was found that this source of scatter had been almost completely eliminated.

Masking the un-diaphragmed prism face prevented grazing incidence reflexions at the quartz-pitch interfaces and so further improved the purity of the output from the monochromator.

The dispersed beam occupied a considerable angular spread, and at every wavelength setting some dispersed light fell on either the ground edges of the auxiliary mirror or the back of the slits. This gave rise to a wavelength dependent scatter which was largely prevented by painting the surfaces concerned matt black.

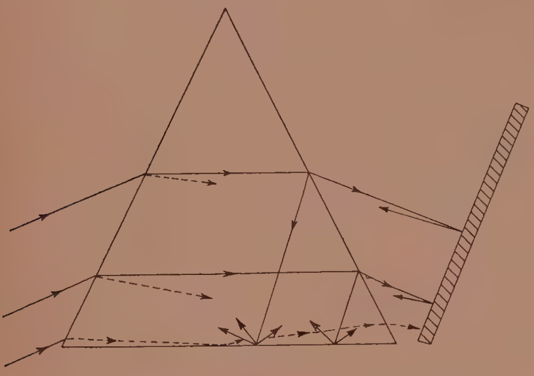


Fig. 2. Unwanted reflexions in the prism

These procedures resulted in a considerable improvement in spectral purity as judged by visual inspection with a direct vision spectroscope, and there was no further shift in the Soret maximum on the addition of a filter.

Our thanks are due to Professor J. M. Yoffey in whose laboratories this work was conducted. This work was conducted with the aid of grants from the Rockefeller Foundation and the Medical Research Council.

REFERENCES

(1) Beckman, A. D., and Carey, H. A. *J. Opt. Soc. Amer.*, **31**, p. 682 (1941).

(2) Saidel, L. J., Goldfarb, A. R., and Kalt, W. B. *Science*, **113**, p. 683 (1951).

(3) Donaldson, R. *J. Sci. Instrum.*, **29**, p. 150 (1952).

(4) Keohane, K. W., and Metcalf, W. K. To be published.

(5) Sidwell, A. E., Munch, R. H., Guzman-Barron, E. S., and Hogness, T. R. *J. Biol. Chem.*, **123**, p. 335 (1938).

(6) Walsh, A. *Nature* [*London*], **167**, p. 810 (1951).

(7) Burch, C. R. Private Communication.

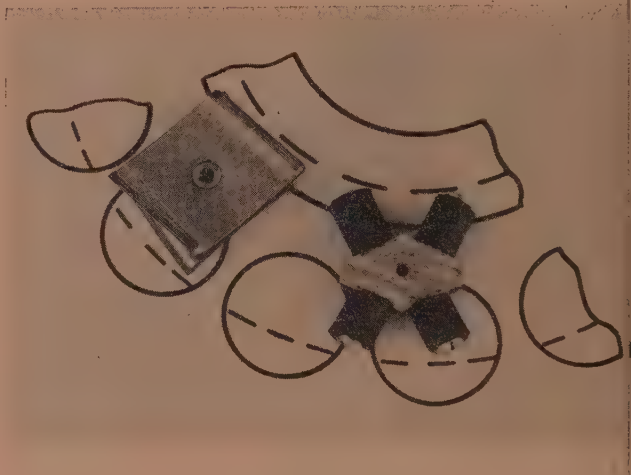
A brush for cleaning decade switch contacts

By A. Gridley, B.E.M., and J. A. Hall, A.R.C.S., B.Sc., F.Inst.P., National Physical Laboratory, Teddington, Middlesex

[*Note received* 6 *July*, 1955]

The type of switch used for the decades of instruments made by H. Tinsley and Co.* has been shown to have a very reproducible contact resistance,† but, owing to the fact that the brushes work in narrow slots in which the contact surfaces are only about 0·25 in. apart, it is not very easy to clean the surfaces. In a Smith resistance bridge which has been described recently† there are fourteen of these switches, each having three slots in parallel, and it has been found worth while to design a special brush for cleaning them.

The photograph shows one of the copper contact brushe and the cleaning brush side by side on a drawing representin a portion of a switch. On the operating arm are two paralle guides which embrace the brushes and hold them in a radia position, while a pin through the central hole in each brus keeps it at the correct distance from the centre. The cleanin brush consists of a diamond-shaped piece of brass, $\frac{3}{16}$ in thick, which can be mounted interchangeably with th normal contact brush, and which carries four short studs o $\frac{1}{8}$ in. diameter brass over which are placed lengths of Hallpren synthetic rubber (made by Hall and Hall Ltd.) of $\frac{1}{4}$ in. externa diameter and $\frac{1}{16}$ in. wall. Retaining shoulders at the end of the brass rods are provided by screws having very shallo domed heads. In the photograph, the broken lines indicat the limits of the slots in the studs and slip-ring, and it wi be seen that the cleaning brush sweeps over a slightly large area than that used by the contact brush.



Contact brush and cleaning brush shown on a drawing of part of a switch

The procedure adopted for cleaning is as follows. Sin the switches are mounted on Perspex (polymethyl metha crylate) carbon tetrachloride (which has very little effect o Perspex) is used as a solvent for the dirty lubricant which to be removed. The copper brushes are all removed an allowed to soak for several hours in the solvent, the cleanin brush is dipped in clean solvent and placed in each of th slots in turn and swept from one end of the travel of th switch to the other and back. It is then removed, wiped an re-dipped in the carbon tetrachloride, and the operatio repeated two or three times. The rubbing surfaces of th copper brushes are smeared with a little Elvolube swit lubricant (Gulf Oil Co.) before they are replaced.

The Hallprene tubing is free from sulphur and is th unobjectionable from the point of view of attack on coppe It swells slightly when immersed in carbon tetrachloride, an the temporary softening aids the squeegeeing action necessa to remove the dirt, while any permanent damage suffere by the Hallprene is very slight and the same pieces of tubi can be used many times.

The work described in this note was carried out as part the research programme of the National Physical Laborator and is published by permission of the Director of t Laboratory.

---

* British Patent 616684, June 1949.

† Barber, C. R., Gridley, A., and Hall, J. A. *J. Sci. Instrum.*, **32**, p. 213 (1955).

Correspondence

On the preparation of precision resolving power test objects

n my paper published on p. 24 of the January issue of this *ournal* the term "Cobb-type" was used in referring to test bjects comprising three black bars separated by spaces of qual width, the length of the bars being five times the width. he use of this nomenclature has been criticized on the rounds that Cobb himself used only two bars.

In describing the three-bar targets, the expression "Cobb-pe charts," as distinct from "Cobb charts," was used eliberately as it was known that Cobb did, in fact, use two ars. His targets comprised two bars with line and space of qual width, and length three times the width giving a square verall pattern. The term "Cobb-type" has been widely sed to denote the three-bar targets in which these two gnificant conditions are satisfied; i.e. line and space of qual width, and length five times the width, again giving a quare overall pattern.

Many workers have stated that there is no difference in easured resolving power whether two- or three-bar targets f this type are employed. This is an additional reason for etaining the present nomenclature, rather than coining a ew term for a target insignificantly different.

lational Physical Laboratory, G. D. DEW
eddington, Middlesex.

A note on the transistor as a thermometer

he fact that the collector current of a transistor varies onsiderably with temperature is well known. The magnitude f the change being such that a 10° C rise in temperature is ufficient to double the current flowing, it seemed possible at the transistor might form a useful thermometer, analogous the thermistor and possessing a similar high sensitivity.

This possibility has been tested using a type 3X/300N nction transistor (by Standard Telephones and Cables Ltd.) the circuit shown in Fig. 1. This is effectively a d.c. bridge

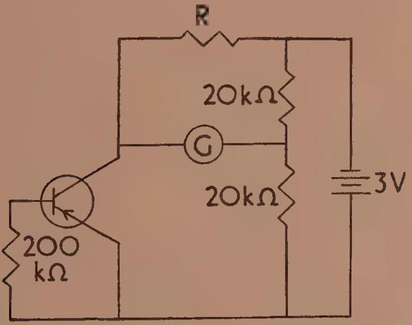


Fig. 1. Transistor circuit used for thermometry. G is a Cambridge short period galvanometer (resistance 25 Ω; sensitivity 300 mm/μA)

nd in the balanced condition the collector current I is $V/2R$. owever, it is not in fact necessary to calculate I as, for the esent purposes, I may be replaced by R. The transistor as enclosed in a thin-walled glass tube immersed in water a Dewar vessel which was fitted with a stirrer, electrical eater and thermometer. Measurements have been made of the value of R required to produce balance at various temperatures with the following results.

T° C	24·97:	25·05:	25·15:	25·56:	26·58:	27·12:	27·82
R	25480:	25120:	24860:	23720:	20930:	19500:	18050

T° C	28·29:	29·24:	30·32:	31·89:	33·20:	34·38
R	17020:	15230:	13420:	11230:	9680:	8500

The dependence of collector current, and hence of R, on temperature is of an exponential form and Fig. 2 shows a plot of $\Delta \log R/\Delta T$ against ΔT which, although not constant, is linear. From this it follows that, under the present conditions, the variation of R with temperature may be satisfactorily described by the empirical equation

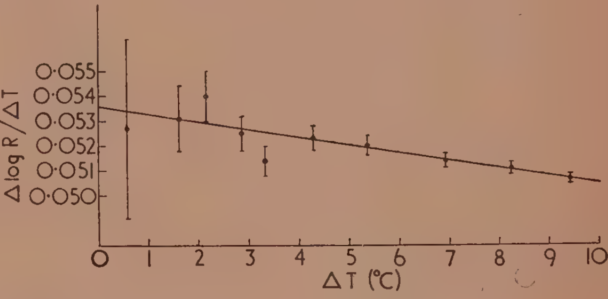


Fig. 2. Variation of transistor equivalent resistance with temperature

The estimated errors are indicated by the lines through the points.

$$\Delta \log R = \alpha \Delta T - \beta \Delta T^2$$

the values of α and β with the particular transistor used being 0·0536 and 0·0031 respectively.

Over a short temperature interval the second term may be neglected; thus if $\Delta T < 0{\cdot}2$° C the error introduced by this approximation is less than 0·1%. To check this point several calorimetric experiments have been carried out in which known heat inputs were supplied to the system *via* the electrical heater and the change in R determined from R/time plots in the usual manner. The results obtained are set out in the table below.

Results of calorimetric experiments

Heat input ΔH *calories**	$\Delta \log R$	$\frac{\Delta \log R}{\Delta H} \times 10^4$
28·06	0·003023	1·077
42·09	0·004565	1·085
52·3	0·005627	1·075
75·24	0·008143	1·082

* The thermal capacity of the system was of the order of 600 cal/° C hence maximum $\Delta T \simeq 0{\cdot}13$° C.

The scatter, of ±0·5%, in the value of $\Delta \log R/\Delta H$ is considerably greater than any effect due to neglect of the β term and is indicative of the limit imposed on the temperature measurements by the precision with which R can be determined. In the present case random fluctuations limited this to approximately ±2 Ω.

From the results obtained it is evident that although the transistor may be used to determine temperature changes with a precision of at least $10^{-3\circ}$ C it is inferior to the thermistor for this purpose owing to its much lower stability.

I would like to thank Dr. G. B. Chaplin and Dr. J. H. Stephen of Electronics Division, Atomic Energy Researc Establishment for much valuable discussion.

A. G. White
Chemistry Division,
Atomic Energy Research Establishment,
Harwell, Berks.

New books

Atomic energy research at Harwell. By K. E. B. Jay. (London: Butterworths Scientific Publications, 1955.) Pp. xii + 144. Price 5*s*.

This volume is in the nature of a progress report and gives the reader a good general picture of what has been happening at Harwell since the account published in 1952.* Some sections, however, deal with the work done over the whole of the Establishment's eight years of life, for it is only now that the information can be released.

The report is divided into two parts. The first (76 pp.) deals with the major programmes and is written primarily for non-technical readers. The second part (62 pp.) is written for "scientific readers who have not specialized in the various fields discussed" and deals with selected researches carried out in the last two or three years.

Part I, while a little uneven, is generally good and satisfying; the chapter on the development of electronic instruments which describes clearly and concisely the various counters in use and the associated equipment is an excellent piece of technical writing for the non-specialist. There are, however, occasional lapses, for example, a phrase like "glass heavily loaded with lead . . . " (p. 63) may mislead a non-technical reader not familiar with lead-glass. The standard of technical knowledge assumed varies—some terms being explained, whilst others are not.

Hints of the magnitude of the work and of the problems, technical and human, which have been solved—or almost solved—are given throughout the book; and although few readers will meet them on such a scale, they will profit by reading of the energy and courage with which they were tackled.

Part II opens with an excellent paragraph on the importance of fundamental research. The three chapters in this part deal with research in physics, in chemistry and chemical engineering, and in metallurgy. These divisions, let it be said, however, are not to be taken too seriously since one finds an account of the use of the plane grating in divergent light under chemistry and the effect of radiation on long chain polymers under metallurgy.

The glossary, for "the non-scientific reader" is a valuable feature, which might usefully have been extended. Perhaps the "nicknames" of the reactors such as Dimple, Zephyr, Bepo, etc., might have been included in the glossary for the reader forgets which particular type they are. Incidentally, remembering that the origins of names in technology are soon forgotten or lost, one wonders whether some international agreement might be made, before it is too late, by which the name of a reactor clearly indicated the type to which it belonged, and was the same throughout the world. The confusion in the naming of scientific instruments is well known, and will perhaps serve as an awful example to nuclear physicists and engineers to act before it is too late!

This book deserves to be widely read. It will make the reader generally, even if vaguely, aware of the remarkab advances in pure and applied physics, including scienti instruments, resulting from the work at Harwell; it w show him how outsize scientific and technological probler are tackled; lastly, but by no means least, it contains sor excellent examples of scientific writing.

H. R. Lang

---

* *Harwell—the British Atomic Energy Research Establishment*, 1946–1951 (London: H.M. Stationery Office, 1952).

Recent advances in optics. By Dr. E. H. Linfoot. (Londo Oxford University Press, 1955.) Pp. ix + 286. Pri 50*s*.

Dr. Linfoot's book is the first optical treatise of maj importance which has come from Cambridge for many yea It is, however, no true descendent of the classical treati on "geometrical optics," being more closely related in subject-matter to the optical work of astronomers such Airy, Bessel, Foucault, Struve and others. The ma background interest here is in connexion with Schmi cameras and associated systems, the physical aspects of the residual aberrations, and the balancing of such aberrations produce the optimum definition in a known surface. Practic problems in the control of figuring of mirror systems a reflected in theoretical discussions of the Foucault test. A exception to the predominant "astronomical-instrume flavour" is found in the section dealing with the images partly coherent objects.

As its title suggests, the book represents some of the maj theoretical investigations of the last thirty years, and gives good idea, not only of the author's own work, but also others who have worked at such problems.

Though work of this character has already led to importa improvements in optical designs, the results must, in sor cases, be regarded as provisional. Physical studies of "st images" have not yet led to any well-proved general asses ment of the effect of geometrical aberrations on ima quality, and as far as a discussion is concerned with t "effective radius" of an image patch defined as a radius gyration expressed in terms of ray-density there is occasi for some reservation of opinion though indeed the meth of investigation is most instructive and aims at a satisfacto precision in statement. Astronomical requirements, too, m differ vitally from those in other fields.

Some readers may think that certain terms, "princip point" for example, have been appropriated in an undesirab way; some may wish that the statements of the introducto paragraphs had been less condensed; but these are min points. Readers with the necessary mathematical equipme will find in these pages a very illuminating and semin account of modern endeavour in theoretical optics.

L. C. Martin

The scope for electronic computers in the office. (Londo Office Management Association, 1955.) Pp. 1 Price 15*s*.

This book is based on the papers presented at the Natior Conference of the Office Management Association in M 1955 by eleven firms producing electronic computers in t untry. After an introductory chapter by Lord Halsbury ving a brief outline of the first ten years' experience in the ectronic computer field and possible applications in the ture, the remaining chapters are each devoted to accounts the specific machines which are being produced by each the firms.

The descriptions pay special attention to the application the machines to commercial work and the examples chosen e all drawn from that field. They include wages calculations, .A.Y.E. tables, invoicing and production planning and many hers of a similar nature. The papers have been consciously yled in a rather popular manner but have avoided that cetiousness which is often noticeable in presentations tended for the commercial world.

There is much that is of interest to the scientific user who ishes to know what machines are available in this country nd to obtain a broad idea of their respective capabilities. nformation of this nature is very much in demand at the resent moment. J. H. Wilkinson

otes on applied science No. 12. Calibration of temperature measuring instruments. (London: H.M. Stationery Office, 1955.) Pp. iv + 47. Price 2*s*.

his booklet, addressed to industrialists and technicians, sets ut primarily to give an account of the methods, and of the rinciples on which they are based, used by the National hysical Laboratory in the standardization of thermometric nstruments. The relationship of the International Tempera- ure Scale to the fundamental thermodynamic scale and its aintenance by means of a series of standard instruments is arefully explained. This is followed by a description of the omparison of working standards with the standard instru- ents and finally, of the use of the working standards in outine testing. The descriptions of apparatus in use at N.P.L. are, on the whole, clear and very well illustrated, though it must be admitted that the section on the realization of the boiling point of oxygen leaves this reviewer in the dark. The later chapters contain a wealth of practical information (not easily found elsewhere) which will be appreciated by those who have to calibrate temperature measuring instruments in their own laboratories.

K. M. Greenland

Magnetic amplifiers. By Dr. Herbert F. Storm. (London: Chapman and Hall Ltd., 1955.) Pp. xix + 545. Price 108*s*.

After three chapters on magnetics there follow seventeen chapters on the theory of magnetic amplifiers and here the field is well covered: the different types of amplifier, the different connexions and effects of circuit parameters are all discussed. The subdivisions into short chapters and sections are a help in finding information about each particular type. Two chapters on components—core and coil assemblies, and metallic rectifiers—and seven chapters on applications complete the work.

Whilst well documented by references the authors do not pretend the list to be complete and they give a reference to a paper which covers this aspect from 1887 to 1951. Despite the size of the book the information is of a rather general nature in many places and although the material may be available in certain parts of the book there is no one place where a typical design is worked out from the initial specification of job to be performed to the required details of core size, winding data, etc. This is something lacking not only in this book but in others on this subject: it is felt that such an example would help considerably those who have to design magnetic amplifiers as distinct from those who only use them in some application. A. J. Maddock

---

Manufacturers' publications

Copies of the publications mentioned in this section are normally obtainable gratis from the manufacturer named.

Electronic and nucleonic instruments. Ericsson Telephones td., Instrument Division, Beeston, Nottingham. A leaflet ummarizes a range of instruments including a pulse generator, terval timer, electrometer, radiation monitor, scaling and robe units and batch counters.

High vacuum pumps. Naresco Equipment Corporation, 60 Charlemont St., Newton Highlands 61, Mass., U.S.A. ulletin P-3 supplies details of a range of National Research orporation rotary gas ballast pumps. It also contains omographs and other information of use in designing a acuum system.

Electrical equipment. Sunvic Controls Ltd., Eastern ndustrial Estate, Harlow, Essex. A booklet entitled Progress in Instrumentation" summarizes the literature vailable from this firm. The products have various uses, ut have been grouped into the following categories: process ontrol instruments; industrial instruments; scientific instru- ents; domestic products.

Inductance bridge, resistance box and oscillator. Furzehill aboratories Ltd., 57 Clarendon Road, Watford, Hertford- hire. Leaflet B.1 describes an incremental inductance ridge, type B.800. Leaflet R.1 describes a 40 W decade esistance box, type R.600. Leaflet G.4 describes a wide- ange, low-frequency oscillator, type G.425.

Switches and signal lamps. Arcolectric (Switches) Ltd., Central Avenue, West Molesey, Surrey. Catalogue 129 lists full details, including prices, of a range of switches, signal lamps and associated equipment.

Colour filter glass. Chance Brothers Ltd., Glass Works, Smethwick 40, Birmingham. A catalogue gives full specifications of various types of colour filter glass.

Transfer function analyser. The Solartron Electronic Group Ltd., Thames Ditton, Surrey. A leaflet describes a transfer function analyser which consists of a low-frequency, decade oscillator and a low-frequency, phase-sensitive voltmeter.

Instrument cases. Alfred Imhof Ltd., 112–116 New Oxford Street, London, W.C.1. A catalogue contains illustrations of a range of cases and accessories and provides full specifications including prices.

Cone and plate viscometer. Ferranti Ltd., Hollinwood, Lancashire. A brochure gives full details of the Ferranti–Shirley cone and plate viscometer.

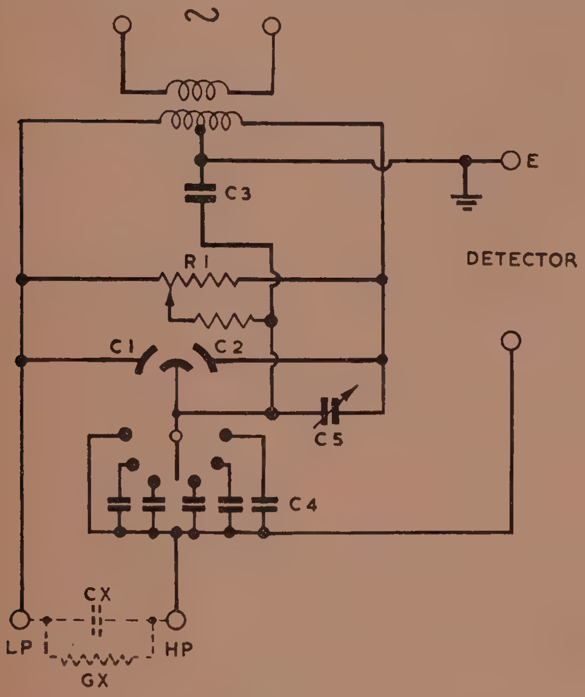
Vibration generator. Goodmans Industries Ltd., Axiom Works, Wembley, Middlesex. A leaflet provides full specifications of a range of vibration generators and ancillary equipment.

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or improv products. The Institute of Physics assumes no responsibility for the statements given below: information for these has be taken from literature supplied.

Radio-frequency capacity bridge. Electronic Tubes Ltd., Kingsmead Works, High Wycombe.

A circuit diagram of this bridge is shown in the figure. It is designed for measuring valve inter-electrode capacities in the range 10^{-3} to 100 pF. The high frequency used (1 Mc/s) avoids many of the complications due to conducting films on insulators. The capacity C_X with conductance G_X is measured as a three-terminal network, two terminals being connected to *HP* and *LP* and the third to earth. The operation of the bridge is as follows. With C_X disconnected, the differential condenser C_1C_2 is set to zero and R_1 and C_5 are adjusted to balance. C_X is then inserted and the bridge is balanced by adjustment of C_1C_2 and R_1. The capacity and conductance are obtained by multiplying the scale readings on C_1C_2 and R_1 by a factor corresponding to the setting of C_4. The readings are unaffected by capacities to earth from *HP* and *LP* provided these are less than 300 pF; the makers claim an accuracy of 1% of full scale on the capacity readings and about 5% on the conductance readings. The bridge is built in two separate units, a crystal controlled 1 Mc/s oscillator and power supplies being in one unit and the bridge and detector in the other. The latter consists of a frequency changer with a crystal-controlled oscillator (1·465 Mc/s) followed by a two-stage amplifier with automatic gain control, a detector and magic eye. Both units are suitable for either bench or rack mounting. Jigs are available for measurements of inter-electrode capacitance of all common valves; further jigs are under development.



Circuit of radio-frequency capacity bridge

R_1 = conductance balance.
C_1, C_2 = main balance condenser.
C_3 = fixed first range adjustment.
C_4 = range adjustment.
C_5 = zero adjustment.

Dynamic pickup. Dynamic Instrument Co. Inc., 28 Carleto Street, Cambridge, Mass., U.S.A.

A small, low-range pressure transducer, the Dynisc measures either gauge or differential pressure in the rang 0·00 to 0·05 and 0·00 to 1·00 lb/in.^{2}. It consists of a $1\frac{7}{8}$ i diameter beryllium-copper bellows fastened to the rig pickup case and connected to a special, strain-sensitiv resistance bridge. Separate input pressures are applied either side of the bellows through threaded connexion hol in the pickup case. Movement of the bellows produces electrical output signal proportional to the difference betwee the two pressures. The transducer is designed to withstar overloads up to 15 lb/in.^{2}.

The pickup is housed in an aluminum case $2\frac{1}{4}$ in. in di meter and $1\frac{7}{8}$ in. in height. Two $\frac{3}{16}$ in. diameter tapped hol are provided for pressure input connexions to rigid syste piping. Units can also be equipped with standard, frictio type, hose nipples for flexible tube connexions. The tot weight is $\frac{1}{2}$ lb.

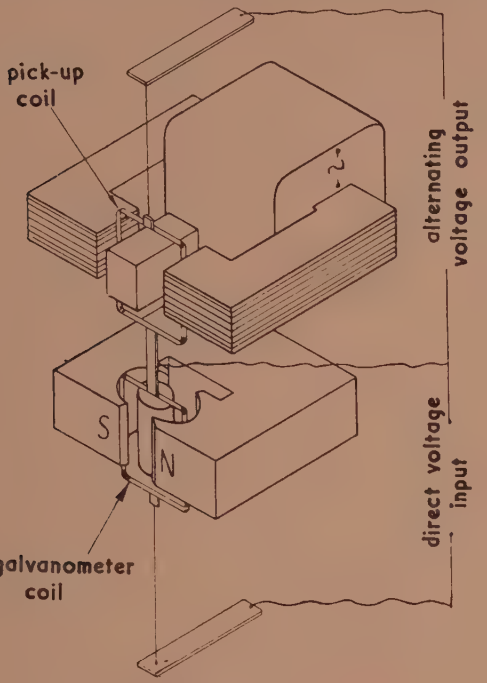
The unbonded strain-gauge sensing element weighs 4 The resistance-bridge assembly is available for a.c. or d. excitation voltages of 6, 12 or 15 V, for bridge resistances 350, 600 or 800 Ω, and minimum full-scale outputs of 2 40 or 50 mV, respectively. It is claimed that the resolutic is 0·02% of full scale and measurements are accurate 0·5% at 70° F. The minimum insulation resistance fro pickup case to ground is 100 MΩ, and the makers state th hysteresis is no more than 0·25% of full scale.

Galvanometer modulator, microvoltmeter and nanoammete W. G. Pye and Co. Ltd., Granta Works, Cambridge.

The basic unit of these instruments is the galvanomet modulator, which is a device for converting an input dire current or voltage into an alternating potential. As the figu shows, the instrument consists essentially of a taut suspensic moving coil galvanometer. A second coil, rigidly attach to the galvanometer coil, lies in an alternating magnetic fiel Rotation of the moving coil assembly causes an alternati output to be induced in the second coil. In the case of t galvanometer modulator type 11350, when the energizi coil is excited by 0·15 A at 6·3 V (50 c/s), the volta gain (r.m.s. alternating output ÷ direct voltage input) approximately 1500. The moving coil unit has a fr period of 2·8 s. The 40 Ω coil requires 700 Ω for critic damping.

The microvoltmeter type 11340 incorporates a galvan meter modulator whose output is applied to a single-sta valve amplifier. The output of this operates a phase-sensiti rectifier which produces a current passing through the par meter and a feedback resistor. The voltage developed acro the latter is connected in series to the input circuit so as oppose the input signal; this negative feedback stabilizes t system against changes of amplifier gain. On the mo sensitive range, the 100–0–100 μA panel meter gives full-sca deflexion for an input of ±10 μV. The input resistan under these conditions is 40 Ω and the response time $\frac{1}{2}$ The makers claim that the long-term zero drift after t initial warming up period does not exceed 1 μV/h; sho erm fluctuations depend on mains variations and vibrations, out seldom reach ½ μV.

The nanoammeter type 11345 is basically similar to the nicrovoltmeter except that a different type of galvanometer nodulator is used excited at approximately 100 kc/s and giving



Principle of galvanometer modulator

reedom from error due to any 50 c/s content of the input ignal. On its most sensitive range, it indicates $\pm 10^{-8}$ A or $\pm 10^{-5}$ V) full scale and has an input resistance of 1000 Ω.

Temperature controller. Airmec Ltd., High Wycombe, Buckinghamshire.

The temperature sensitive element of the temperature control init type N856 forms one arm of a bridge circuit. One of the other arms is made variable to provide an adjustment of emperature over a wide range. The bridge out-of-balance oltage is amplified and used to operate two separate relays *ia* a phase sensitive detector. The relays are arranged to perate at slightly different temperatures, the difference being djustable from 0 to 3° C.

Two types of sensing elements may be used. The resistance lement normally supplied is a flat winding on mica insulated y mica sheets and measures approximately 2 × 1 in. The ead wires have glass-fibre insulation. For immersion in iquids or for use in a corrosive atmosphere or at temperatures bove 300° C a sealed platinum-bulb thermometer may be ised as the sensing element. This detector is in the form f a rod 2¼ × ¼ in. diameter and is provided with a nut and vasher assembly for sealing the aperture in which it is fitted.

The unit has six overlapping ranges selected by a wander ead and terminal block, covering a total range of −46 to 00° C for the flat sensing element and −96 to 428° C for he platinum-bulb element. A fine control within each range s provided by an adjustable potentiometer which carries a to 50 arbitrary scale. Both relays operate and release on a hange in control resistance of approximately 0·1%. This represents a differential of 0·25° C for the flat resistance element and 0·4° C for the platinum-bulb element. Both relays are rated at 5 A at 230 V.

Each relay may be connected either to open or close on rise of temperature and may be set to operate at the same

Temperature control unit

temperature or at temperatures differing by up to 3° C. The unit can therefore be used to control not only electric heating elements but also heating or cooling processes using motor-controlled valves.

Low inertia integrating motors. Electro Methods Ltd., Caxton Way, Stevenage.

A range of permanent magnet d.c. motors has been developed in which the factors making for non-linearity of the voltage-speed characteristic have been minimized. The motors are therefore suitable for integrating small voltages on a time basis. It is claimed that the smaller models will operate directly off a photocell or thermocouple. The following data illustrate the performance of the smallest of this range of motors.

Nominal voltage, 1·5 V;
Starting voltage (no load), 4·2 mV;
Starting current (no load), 1·5 mA;
Increase for 1 g.cm torque, 42 mV, 15 mA;
Speed ratio between starting and limiting voltage,
  1 : 1000 (no load) or 1 : 100 (1 g.cm torque);
Time constant, 10·5 ms.

Electric soldering iron. Enthoven Solders Ltd., 89 Upper Thames Street, London, E.C.4.

The Superspeed electric soldering iron, manufactured by Scope Laboratories of Australia, can be used on 2·5 to 6·3 V supply; a 4 V transformer is normally supplied with it. The "iron" can be switched on by a light thumb pressure on the switch ring on the handle and it heats up in 6 s. The "iron" is 10 in. long and weighs 3½ oz; the makers claim it to be more powerful than a conventional 100 W "iron."

Notes and comments

Elections to The Institute of Physics

The following elections have been made by the Board of The Institute of Physics:

Fellows: R. N. Aldrich-Smith, V. Barocas, W. T. Cowhig, B. Dayal, A. Edwards, W. P. Fletcher, R. W. G. Haslett, J. L. Howarth, P. G. Klemens, H. Kronberger, L. N. D. Lucas, B. Meltzer, W. M. M. Muller, J. B. Nelson, J. Norbury, J. F. Richardson, R. W. Stanford, V. H. Taylor, G. A. Whitfield.

Associates: G. A. Aldous, D. R. Ashworth, J. Bateman, A. E. Beck, S. Bingham, E. W. Billington, B. J. Brown, J. S. Buchanan, T. G. Bullen, E. H. Carmen, J. A. Chapman, S. M. Clark, A. Cook, N. D. Cowell, R. Crosland, T. H. Dennis, F. Domanic, R. D. Fortune, L. K. Ecclestone, D. A. Gill, L. R. Gray, J. L. Grimsdell, A. H. Harris, R. D. Harrison, K. Hickson, D. W. Hill, J. W. Holmes, E. S. Hotston, R. E. Jahn, B. D. James, A. H. Jiggins, A. K. Jonscher, J. W. Kennedy, C. G. Kennell, D. G. Lampard, J. S. L. Leach, J. A. Lucken, F. B. Malkin, N. Marshall, J. McCulloch, K. B. Mather, J. R. Marsden, J. I. Mitchell, K. P. Nicholson, P. A. O'Brien, N. S. Parker, R. B. Pepper, C. D. Pomeroy, P. Popper, T. R. Prentice, B. Pickup, R. E. Price, B. W. Purslow, D. R. Quested, R. C. Reid-Jones, C. B. Richards, A. S. Roberts, S. Scregg, D. J. Smith, R. J. S. Sherwin, D. B. Shina, G. W. Smith, R. Steadman, D. W. Stops, T. Studley, A. G. Thomas, B. S. Thorton, G. L'E. Turner, P. B. Wallis, W. W. Williams, G. B. Woffinden, S. J. B. A. Wyard, D. J. C. Yates.

Seventy-seven Graduates, twenty-one Students and eleven Subscribers were also elected.

The availability of places for physics students in universities and technical colleges

The September *Bulletin* of The Institute of Physics contained a report on the availability of places for physics students in universities and technical colleges. It was based on a survey made by the Institute after the Board decided in November 1954 to investigate the facilities existing in universities and technical colleges for the education of physicists and of the extent to which these were at present being used. Among the reasons which led to this decision were the public discussion of the need to develop facilities for higher technological education (to which discussion the Institute has contributed over the past few years), and various reports that had been presented to the Board on the difficulty experienced by certain technical colleges in securing students for courses in physics for which the colleges were well equipped and which had been running, in some cases, for several years. The report was based on information supplied by twenty-seven universities and fifty-three technical colleges.

The comments of two of the Institute's committees, the Education Committee and the Membership and Examinations Committee were also published. These comment begin by stating: "The data presented in the accompanyin report clearly indicate that existing facilities for the educatio of physicists in universities and technical colleges in Grea Britain are more than adequate for the number of student who wish to read for an honours degree in physics and wh leave school with qualifications normally regarded as essentia for admission to the honours course."

The report and comments have been reprinted with th title *The availability of places for physics students in univer sities and technical colleges* and copies are available, free o charge, from The Institute of Physics, 47 Belgrave Square London, S.W.1.

Conference on plant and process dynamic characteristics

The Society of Instrument Technology has arranged conference on plant and process dynamic characteristic with particular reference to the information required in th design of automatic control systems. The conference will b held in the Engineering Laboratory, Cambridge, fror 4 to 6 April, 1956. Its main object is to provide an oppo tunity for process control specialists and those who hav had considerable experience of the practical problems c the determination of plant and process characteristics t meet and discuss their work. Each session of the meetin will be opened by the presentation of a short paper by speaker invited by the Organizing Committee, but othe who have material to contribute in the form of short pape or reports relevant to the theme of the conference are invite to communicate as soon as possible with the Conferenc Secretary. Proceedings will not be published in full, but th contributions are expected to form the bases of pape suitable for publication in the transactions of the society, c elsewhere. Further details may be obtained from Th Society of Instrument Technology 1956 Conference Secretar Engineering Laboratory, Trumpington Street, Cambridge.

British Journal of Applied Physics

Contents of the November issue

CONFERENCE REPORT

Summarized proceedings of a conference on the structures and textures metals—London, October 1954. By K. Robinson and E. G. Steward.

ORIGINAL CONTRIBUTIONS

Reduction of noise in photoconductive cells. By R. E. Burgess.

Determination of the velocity of ultrasonic vibrations in molten salts. By N. Richards, E. J. Brauner and J. O'M. Bockris.

The scanning electron microscope and its fields of application. By K. C. Smith and C. W. Oatley.

Stability criteria for an electrical or mechanical system with distributed paramete By A. S. Gladwin.

Creep and static friction. By R. T. Spurr.

The capacity and field of a cylindrical trough with a plane conductor in the axi plane of symmetry. By H. J. Peake and N. Davy.

NOTES AND NEWS

New books

Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principles, construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Square, London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation of contributions.* (Price 2*s.* 6*d.* including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon application from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, London, E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within 60 days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of address or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £4 per volume ($11.50 U.S.A.), including index (post paid) payable in advance. Single parts, so far as available, may be purchased at 8*s.* each ($1.15 U.S.A.), post paid, cash with order. Orders should be sent to The Institute of Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.

An automatic recording microdensitometer

By W. A. Wooster, M.A., Sc.D., F.Inst.P., Brooklyn Crystallographic Laboratory, Cambridge

[*Paper received* 8 *June*, 1955]

The paper describes an automatic recording microdensitometer based on the Dobson split-beam type of instrument, using a single lamp and single photocell. The shutter is driven at a non-synchronous speed and an electromechanical transducer is used to convert the output to a synchronous frequency. This output is used to operate a servomechanism which moves a straight photographic wedge and also a potentiometer. The output from the potentiometer drives a standard pen recorder. The film carriage has movements of 28·5 cm and 12·5 cm in perpendicular directions and accurate measurements of these displacements can be read on scales permanently in place.

recent years a number of descriptions of microdensito-eters have been published. Two of these are similar in sign to the present apparatus though there are some portant differences between them.(1,2) The present instru-ent, which is now in commercial production, employs a uble-beam system similar to that first introduced by obson(3) and has only one lamp and one photocell. To oid the possibility of mains interference at various stages the electronic system, the present instrument was designed produce a light beam alternating with a frequency removed several cycles per second from 50 c/s or any harmonic of is frequency. Only a.c. amplification is used and no relays e involved. The film carriage can accommodate the largest otographs likely to be produced in normal X-ray diffraction otographs (28·5 × 12·5 cm). The *x*–*y* co-ordinates of y point on the film can be read on two accurate scales thout any resetting of the film on the carriage. The record obtained automatically on a roll of paper up to 100 ft long d the instrument can work unattended for long periods. e ratio of the speeds of movement of the film under test d the paper carrying the record can be changed by 32 : 1 a series of 2 : 1 steps by rotating a handle on the micro-nsitometer. The chart recorder has a further set of speeds hich can be varied in the ratio of 4 : 1. The minimum or aximum speed of the film carriage can be adjusted initially the choice of wheels in a gear box. The rolls of paper can folded to form a flat book, in which form the relation tween the parts of the record is maintained and reference any part is easily made.

OPTICAL ARRANGEMENT

A schematic representation of the paths of the light beams shown in Fig. 1. Light from a lamp *L* travels by two routes the photocell *P*. The lenses D_1, D_2, prisms R_1, R_2 and ndensers C_1, C_2 focus the light on to the absorbing photo-aphic layer. The objectives O_1, O_2, produce enlarged images the photographic films in the planes of the apertures A_1, A_2, d lenses E_1, E_2 and prisms R_3–R_6 produce overlapping ages on the sensitive surface of the photocell *P*. It has been und that the graininess of the wedge made from X-ray film n cause hunting of the servomechanism when the micro-ope objective is accurately focused on the wedge and a all aperture is used. This cause of hunting can be greatly duced by defocusing the microscope without introducing y loss of linearity in the wedge. The plane containing the ght beam passing from the last prisms to the photocell, and shown in Fig. 1 by dotted lines, is horizontal, not vertical. A shutter interrupts the light from the lamp so that four times during each rotation of the motor shaft, light passes along each optical train. The position of the lamp and shutter is so arranged that as one beam is cut off the other is increasing in intensity. The motor drives, in addition to the shutter, an a.c. generator and the phase of this output is always in step with the output from the photocell. The instrument is used throughout as a null instrument: a photographic wedge *W* is moved along its length until the intensity of the light passing through it balances the light passing through the film *F* under test. When the intensities of the two light beams are equal there is no alternating output from the photocell. When the left-hand beam is the stronger there is an output in phase

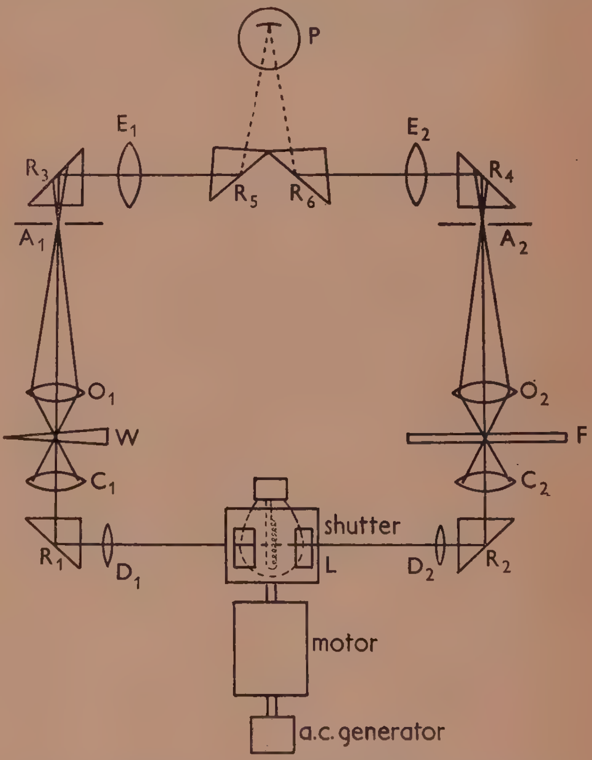


Fig. 1. Diagram of the disposition of the optical components in the present double-beam system

with the output from the a.c. generator. When the right-hand beam is the stronger the phase of the photocell current is 180° in retard relative to that of the generator. The indicating and automatic controlling mechanisms utilize this phase change.

The lamp is a motor car headlamp (36 W) with a straight filament. It is operated from the 50 c/s supply. The condensers C_1, C_2, and the objectives O_1, O_2, are normal microscope components. The limiting apertures A_1, A_2, are made in sizes suitable for the purpose of the investigation. For the study of relatively broad lines an aperture 4 × 1 mm is suitable. With a 16 mm objective the magnification is about twelve times and the width of the portion of the line studied about $\frac{1}{12}$ mm. By using a narrower aperture, say 4 × 0·2 mm, a finer resolution can be obtained though the graininess of the film will often set a limit to the useful minimum area which can be examined. Using optical film, such as 35 mm cinematographic film, and two stages of optical magnification before the limiting apertures, an area of 1/1000 × 1/100 mm permits enough light to pass through to operate the balancing mechanism. An ordinary photocell has been used in this instrument because there is enough light to operate it under usual conditions and it is more convenient than a photomultiplier.

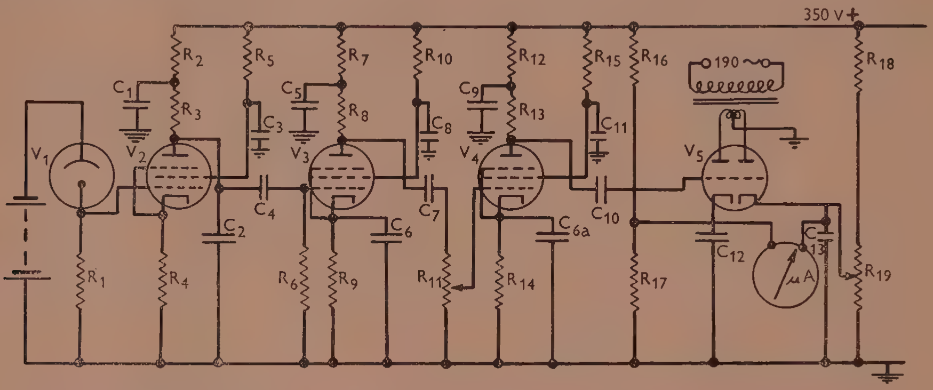


Fig. 2. Circuit diagram of the photocell amplifier and double-triode rectifier

R_1 = 10 MΩ
R_2 = 47 kΩ
R_3 = 250 kΩ
R_4 = 2 kΩ
R_5 = 600 kΩ
R_6 = 1 MΩ
R_7 = 47 kΩ
R_8 = 250 kΩ
R_9 = 5 kΩ

R_{10}, R_{11} = 1 MΩ
R_{12} = 47 kΩ
R_{13} = 250 kΩ
R_{14} = 2 kΩ
R_{15} = 1 MΩ
R_{16} = 94 kΩ
R_{17} = 3·3 kΩ
R_{18} = 94 kΩ
R_{19} = 5 kΩ

C_1 = 4 μF
C_2 = 0·005 μF
C_3 = 0·25 μF
C_4 = 0·005 μF
C_5 = 4 μF
C_6, C_{6a} = 50 μF
C_7 = 0·005 μF
C_8 = 0·25 μF
C_9 = 4 μF

C_{10} = 0·005 μF
C_{11} = 0·25 μF
C_{12}, C_{13} = 1 μF

V_1 = 90 CG
V_2 = EF 37A
V_3, V_4 = 6 J 7
V_5 = 6 SN7GT

THE ELECTRICAL AMPLIFIER AND SERVOMECHANISM

There are three distinct parts in the electrical apparatus used in this instrument. The first part is an amplifier dealing with a signal from the photocell, the frequency of which is different from the 50 c/s or any exact multiple of this frequency. In this instrument a frequency of 190 c/s has been used. The amplified photocell signal is rectified and converted in the valve V_5, Fig. 2, into smoothed direct current. The electrical system is so designed that the direction of the direct current depends upon the relative strengths of the left-hand and right-hand beams of light, while its magnitude is proportional to the alternating part of the photocell current. The circuit diagram and component values are given in Fig. 2.

The second part of this system is called a balance-unit and is an electromechanical transducer. It consists of t microammeter coils mounted coaxially, one A (Fig. moving in the field of the usual permanent magnet of microammeter, the other B moving in a 50 c/s alternati field generated by a coil surrounding horse-shoe shap stampings. When no direct current flows in the first c the plane of the second coil is parallel to the lines of magne force produced by the stampings. If direct current flows one direction through the first coil the phase of the alternati current induced in the second coil is, say, 0°. If the directi of the direct current is reversed, the phase of the alternati current becomes 180°. The magnitude of the alternati current is proportional to the direct current flowing in t first coil. A spiral spring C maintains the coils in a giv setting when no current is flowing. The natural mechani

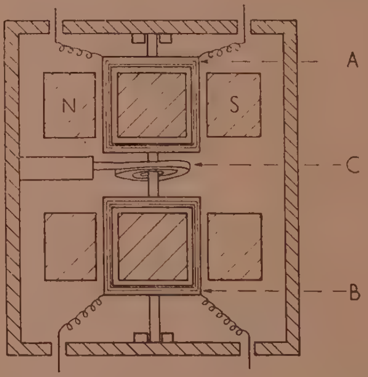


Fig. 3. Diagram of the balance unit showing in the uppe half the d.c. coil and in the lower half the coil moving i the alternating (50 c/s) magnetic field

frequency of oscillation of the coils in their pivots is ab $\frac{1}{10}$ s. (This time must be short compared with the time ta by the recorder pen to traverse the chart.) An adjustmen provided on the control spring so that the plane of the coil is made parallel to the lines of force when no di current is passing. The output of the a.c. coil has a freque of 50 c/s and by means of the electromechanical transduc ansformation of the signal from direct current to 50 c/s made.

The third part of the electrical system is a conventional) c/s amplifier which operates the balance motor. This is a vo-phase motor developing 10 W and drives the wedge into ne position where no a.c. signal is given out by the photocell.)epending on whether the dense end of the wedge is on the ght or the left in its holder, it is necessary to ensure that the hase of the output from the amplifier is 90° in advance or in etard of that of the main supply which feeds the other coils f the balance motor.

To sum up, the essential features of this system are as ollows: (*a*) the balance reading of the wedge is independent f the sensitivity of the photocell, but depends only on the ouble triode, V_5, having the same anode currents in both alves for a given grid voltage; (*b*) spurious effects due to 00 c/s illumination in the main lamp and in the room are voided by the shutter producing 190 c/s current.

AUTOMATIC RECORDING

A number of users of microdensitometers already have art recorders and provision has been made in this instru- ent to utilize such devices. The wedge movement is coupled a potentiometer and the output from this is applied to the corder. Synchronous motors are used both in the drive r the film under test and also in the chart motor, so that the ecessary relation between the two movements is attained.

MECHANICAL CONSTRUCTION

The film under test and the photographic wedge are carried parallel tracks which are arranged at right angles to the ane of the light beams, Fig. 4. Stainless steel rods, *a*, are sed to carry the carriages. Each carriage is carried on eight ll-races *c*, those on one side are rigidly fixed to the carriage, hile those bearing on the other rail are mounted on a spring. this way the carriage runs evenly along the whole length its track. The film carriage has a second pair of rails *b*, ounted on the lower carriage so that the film may be moved two directions at right angles. The ranges of movement 29 cm along the lower rails *a*, and 12·5 cm along the per rails *b*. This movement is great enough to accom- odate the films from 19 cm powder cameras and also the ual Weissenberg and oscillation cameras. The long move- ent is provided by an accurate worm of ½ mm pitch. A lf-nut may be disengaged from the worm and the film oved by hand to any position. Six speeds of film carriage movement are provided by a gear-box, namely 0·63, 1·25, 2·5, 5, 10 and 20 mm/min. The other movement of the film carriage is manually controlled by the rotation of a screw.

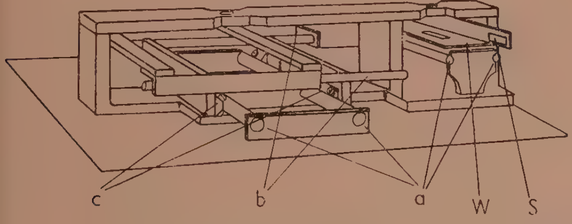


Fig. 4. Diagram of the mounting of the film and wedge carriages. The uppermost plate carries the microscope barrels shown in Fig. 5. The rails *a* of Fig. 4 run from left to right in Fig. 5

The wedge carriage *W* is mounted in a similar manner to the film carriage on eight ball-races. At one end it carries a millimetre scale on glass *S*, the image of which is projected on to a ground glass screen on the front of the instrument (see the general view in Fig. 5). This scale is 50 mm long and is provided with a vernier on the viewing screen. At the opposite end the wedge carriage carries a rack, the pinion of which is driven by the balance motor.

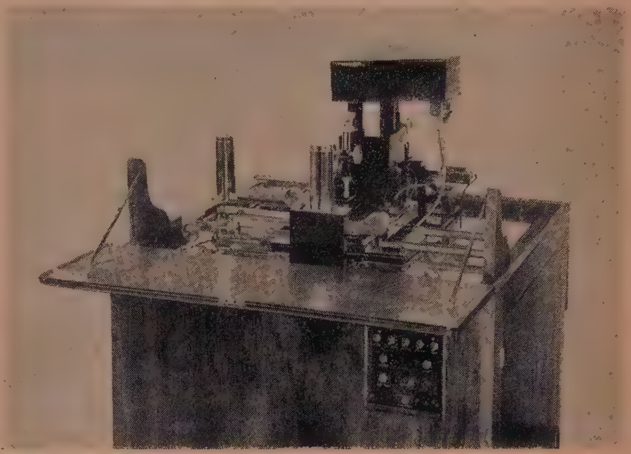


Fig. 5. General view of the instrument with the top cover removed

The shutter is a cylinder of 10 cm diameter, mounted coaxially with the shaft of the motor. Four equally spaced slots are cut in the cylinder, each subtending an angle of 45° at the axis. On the other end of the motor shaft is attached the permanent magnet of an eight-pole dynamo. The stampings of this dynamo are mounted in a stationary cylinder which can be set at the correct position about its axis so that the phase of the alternating current generated corresponds to that of the photocell amplifier.

The balance motor comes into operation when the out-of-balance direct current in the balance unit rises to about 10 μA. Its shaft drives a gear train connected through a rack and pinion to the wedge carriage; it also drives an air paddle at four times the speed of its own rotation. This damping is necessary to reduce hunting of the servomechanism.

OPTICAL WEDGES

The optical wedges can be made in the microdensitometer. The instrument is placed about two metres from an X-ray tube. A strip of lead about 1 mm thick, enough to absorb all the rays coming from the tube, is placed on a fixed part of the apparatus, where it is capable of shielding completely a piece of film placed on the moving carriage. At the beginning of the run all the film is exposed except for one end which is shielded by the lead. As the exposure proceeds the film moves behind the lead screen. In this way a uniform gradient of exposure is obtained along the film. The X-ray tube should be operated at a low voltage (16 kV for CuKα) so that after filtering the radiation consists mainly of the monochromatic component.

OPERATING CHARACTERISTICS

The features of this instrument may be widely varied, depending on what problem is in hand and the following data refer to the study of normal X-ray photographs, using objectives of 25 mm focal length.

Accuracy of reading of position of film carriage: 0·05 mm.
Speed of traverse of carriage: from 0·5–30 mm/min, depending on gears used in gear-box.
Range of density: 0–1, 0–2, 0–4, 1–2, 2–3, or as required.
Accuracy of density reading: The balance position of the wedge can be determined to 1%, so that for a wedge having a density range 0–1 the accuracy is 0·01 in density.
Area of film which may be studied: maximum 1·2 × 1·2 mm; minimum, using sensitive X-ray film suitable for diffraction photographs, 0·07 × 0·07 mm. Using optical film this minimum can be made much smaller.
Speed of traverse of wedge: 2 s for full-scale movement. (This has been adjusted to correspond to the speed of movement of the Honeywell–Brown recorder.)
Electrical supplies: only 50 c/s current is used except for d cells on the photocell and potentiometer.

ACKNOWLEDGEMENTS

The author wishes to acknowledge his indebtedness Dr. A. Nunn May for great help in developing the electror part of this instrument and to Mr. William Duncan f assistance in many of the preliminary experiments. T author's thanks are also due to Mr. E. M. Rank for his sk and patience in constructing the mechanical parts of t instrument.

REFERENCES

(1) Walker, P. M. B. *J. Sci. Instrum.*, **30**, p. 162 (1953).
(2) Brown, J. R., Moneypenny, H. K., and Wakelin, R. *J. Sci. Instrum.*, **32**, p. 55 (1955).
(3) Dobson, G. M. B. *Proc. Roy. Soc. A*, **54**, p. 248 (192

An optical semi-scaler*

By D. W. Hoyte, B.A.,† British Petroleum Co. Research Station, Kirklington Hall, Newark, Notts.

[*Paper first received* 2 *May, and in final form* 11 *August*, 1955]

The instrument described will rescale and print a transparency in one direction only over a continuous range. Its use is demonstrated for the reproportioning of instrumental records taken on film, the illustrations to technical journals, or fashion photographs; and for giving trimetric projections of curves from their plan or elevation views, and stereoscopic pairs of these, including panoramic views from contour maps.

In recording the variations with depth of a physical property in an oil well it sometimes occurs that the amplitude scale differs from one well to the next. For effective visual comparison of one record with another, these scales must all be alike. This demands a change in one direction, while leaving the scale at right angles to it unaltered. It is performed optically by the instrument described here, so the re-scaled curve can be either viewed, traced, or printed on to bromide paper.

Other uses for the semi-scaler are described, which include the production of "solid" pictures from engineers' plans and elevations, and stereographic pairs of these, and of curves in which every ordinate is a given function ($\sqrt{y}$, say) of the original.

The advantages of the semi-scaler over pantograph-type instruments(1) or the method of point plotting(2) are its freedom from friction or preferred direction of travel, and complete elimination of the personal element when prints are taken. Mechanical tolerances and beam parallelism can easily be refined to the point where the accuracy is limited only by the spread of the diffraction patterns that compose the re-scaled picture—about 0·01 in. on the prototype.

THE INSTRUMENT

The principle of the instrument is illustrated in Fig. 1. A parallel beam of light passes through the transparency to be rescaled, to cast a shadow in another plane. There will no change of scale for any lines *J* in the transparency th are parallel to the line of intersection of the two planes, *P* but lines in the transparency *K* that are perpendicular to *P* will have either longer or shorter shadows, depending on t angles between planes and beam. For the right-angle betwe the original lines to be preserved between their shadows, *P* must be perpendicular to the beam.

The layout of the prototype instrument is shown Figs. 1 and 2. The light source is a 250 c.p. Pointolite the left of the operator. The parallel beam is formed the optical system contained in the tube between the la and the main body of the instrument, from which it issu horizontally.

The field of light is the size of the main lens, 5 in. diameter. To increase the length of a transparency that c be dealt with before moving it along, the field is extended reflecting the beam vertically with a mirror that can tra in the direction of the optic axis. The transparency a shadow planes are of glass, mounted in wooden fram They tilt about mutual hinge points on the peaks of wooden chassis. A cowl helps to shield the shadow fr extraneous light and serves to brace the two slotted clamp bars for the top tray. They allow the top tray to rise 60° above the horizontal, and the lower tray to drop to below, giving a continuous range of $\times 2$ to $\times \frac{1}{2}$. T transparency is held between the glass sheets of the film tr For ease of access, the hinge of the upper tray breaks so t it can be lifted.

The hinge line is the direction of no scale change. assist in setting up the transparency this is shown by fidu lines etched on the lower tray. Two pairs of lines are mark

---

Note added in proof. My attention has been drawn to an instrument based on a similar principle described by Mr. R. N. Bracewell on p. 37 of the January 1955 issue of this *Journal*.

* British Patent Application No. 720 676

† Now at Imperial Chemical Industries, Ltd., Billingham, Co. Durham.

actly 3 in. apart, so scale changes can be set directly from e separation of their shadows on the upper tray.

The mirror is supported kinematically to run on two rails circular cross-section. The tolerances in the flatness and rallelism of the rails corresponding to give a maximum rror in the shadow can easily be calculated using radian easure: 0·005 in. in this instrument for a maximum error f 0·01 in.

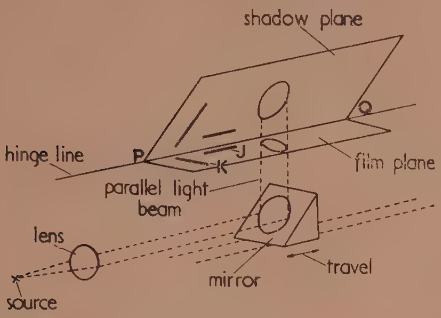


Fig. 1. Field extension by travelling mirror. Instrument set to enlarge

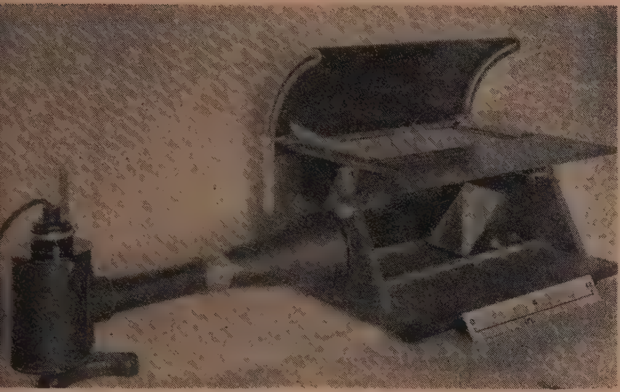


Fig. 2. The prototype instrument, set to reduce

The beam must be in a plane perpendicular to the hinge ne *PQ*. The direction of the beam in this plane is un-nportant, but it must not change when the mirror moves r it will alter the scale change. The perpendicularity adjust-nent is made by varying the height of the rear V-runner on ne mirror or, preferably, by vertical movement of the ointolite source. It is tested by observation of the shadow ast by orthogonal lines with one of them parallel to the hinge ne.

The mirror travel must be smooth to give an even exposure hen printing. A thread passing round a pulley that is irned by hand works very well. With the illumination used ere, bromide paper requires an exposure of about 2 s, orresponding to a mirror speed of 1 in./s, ½ turn/s of the andle.

The main lens is biconvex, 5 in. in diameter, 10 in. in focal ngth. An ordinary cheap magnifying glass was used. fter extending the field with a travelling mirror, a mask as used at this lens to cut out the parts of the beam which e most distorted by spherical aberration, leaving an aperture f 2 × 2¾ in.

The only other aberration which might have affected the adows, namely chromatic, was not observed. Its effects are in any case minimized in the finest work, where photographic prints are taken, owing to the colour selectivity of the paper.

Placing the Pointolite source at the focal point gave a beam with a divergence about that of sunlight, 0·01 radian, and the shadows were correspondingly blurred. The Pointolite was therefore replaced by its image ⅕ size, produced with a biconcave lens.

Focusing to obtain a parallel beam is tested visually, comparing the shadow cast by an orthogonal grid with a similar grid. From Fig. 1, lines perpendicular to the hinge will have shadows that diverge if the beam is not parallel. This is the difficulty found if reproportioning is attempted by tilting the plate in a photographic enlarger.

APPLICATIONS

Rescaling of oscillographic records. The semi-scaler was first conceived and primarily designed to change one scale of measurements recorded as irregular curves on photographic film about 3 in. wide. Fig. 3 shows the rescaling of a record where one scale was left unchanged, and the other scale successively magnified and diminished.

The shadow can be traced, or if the shadow is cast on to bromide paper, a print is obtained of the rescaled film. It is a "negative" which can either be used directly, or photostated to give a "positive" with the further possibility of an overall scale change.

The need for an instrument such as a semi-scaler to aid in the interpretation of such curves is clear from Fig. 3. It is not at all obvious that Fig. 3(*a*) and (*b*) are records of identical phenomena. When phenomena that are not quite identical have been recorded on different scales, visual comparison is almost impossible until they have been rescaled with an instrument such as this. It not only reproduces the grosser points with perfect accuracy, but retains that less definable quality, the character of a curve, on the new scale. Even in a direct trace by a skilled hand this quality is lost.

Reproportioning graphs. In reproducing graphs it is sometimes useful to reproportion the curves. Such curves cannot be replotted and drawn by hand as it is, again, nearly impossible to give the new curve its correct character. It was in an attempt to overcome this that Bainbridge-Bell(1) invented his mechanism of links, pivots and trolleys. However, a photograph of the offending graph gives a negative on celluloid. When this is reproportioned by printing in the semi-scaler, a positive is obtained that is the correct size, and quite untouched by hand.

Trimetric projection. Trimetric projection is one of the easiest ways of representing a three-dimensional object on paper whilst showing great realism. From their co-ordinates in space, points are plotted using a special scale (which is commercially available). A cube appears as Fig. 7. If points are joined by straight lines, these can be ruled in. If by curves, then sufficient points along the projected curve must be plotted for it to be drawn by hand.

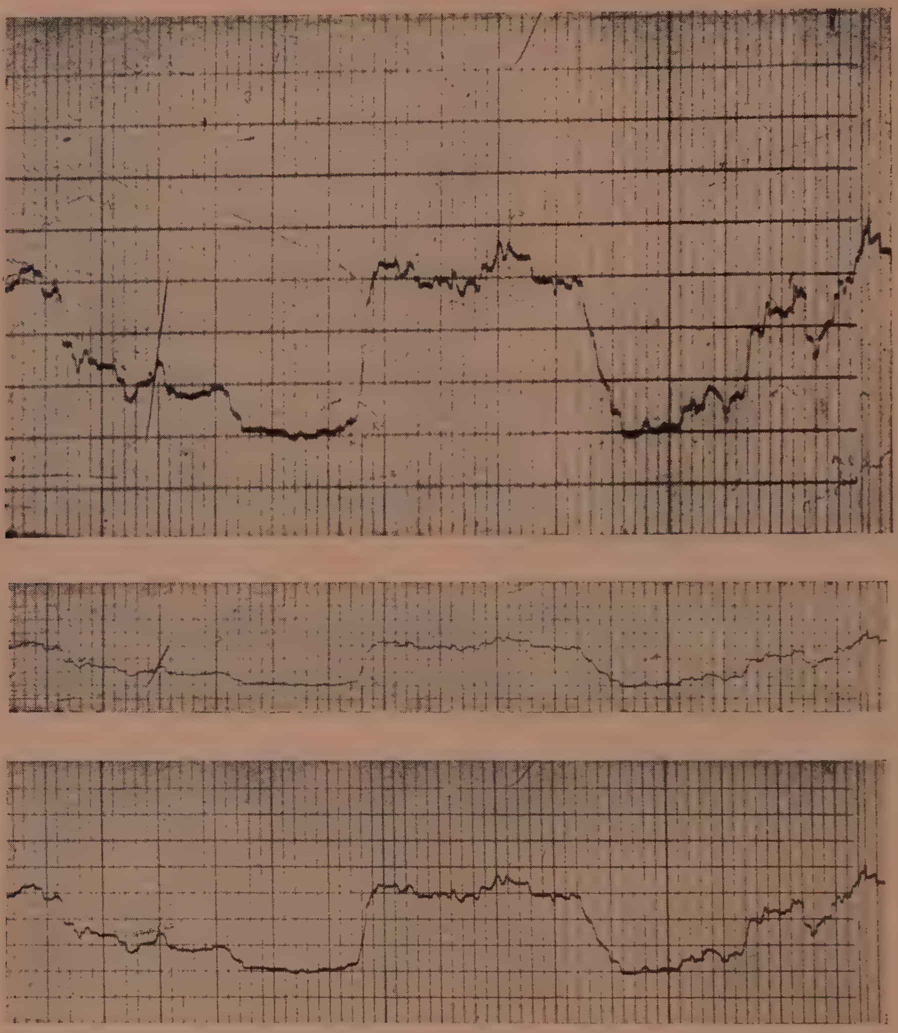
Sometimes, however, such curves have already been drawn in plan or elevation views, but the trimetric projection is required so that a complex structure can be visualized by people unfamiliar with the engineering drawings. This replotting can be very lengthy.

Since the semi-scaler is fundamentally a projecting apparatus using parallel rays it must deal with this case. The calculation is set out below for the setting up of the semi-scaler for trimetric projection. It can be reduced to a simple routine procedure.

Fig. 4 illustrates the elevation of some gear teeth, and the trimetric projection. The orthogonal axes are included in the projection to give the orientation. The projected curves for this figure were printed photographically, minimizing personal error in the construction, and the straight lines were drawn with a trimetric scale.

Since the semi-scaler gives an exact geometrical projection on to the shadow plane of anything that is placed in the beam of light, it can be used for the trimetric projection non-planar curves also. If, for instance, the curve is on t surface of a cylinder, it is drawn on acetate film that is th held in that form by circular end-pieces. The cylinder film is simply placed in the beam at the appropriate an and the shadow of the curve is traced.

The idea of the realistic graphical presentation of an obj from its drawings of plans and elevations is developed to fullest in the stereoscope. A pair of trimetric projections


(*a*) Ordinate magnified.

(*b*) Ordinate diminished.

(*c*) Original view.

Fig. 3. Prints of a rescaled photographic record

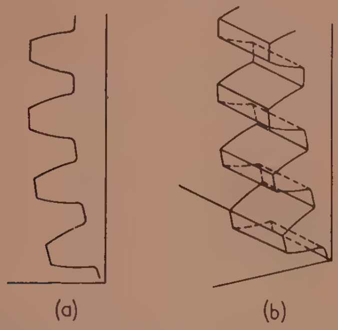


Fig. 4. Trimetric projection from gear wheel drawing (*a*) Elevation. (*b*) Trimetric projection.

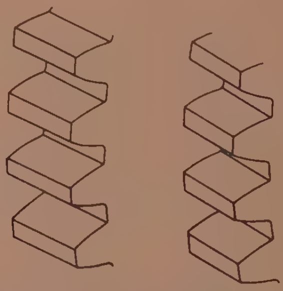


Fig. 5. Stereoscopic pair produced from plan an elevation drawings

ade using the same angle of depression but with a difference about 15° in azimuth (e.g. Fig. 5). When the pair are ewed through a stereoscope the object stands out as though uly three-dimensional. For the illusion to be complete, not ly must the two pictures be very good projections, but the ne densities must be the same in each, conditions that are lfilled by printing them with the semi-scaler.

Setting up for trimetric projection. In the trimetric proction, the usual orthogonal axes of the engineers' plan and evation drawings are projected on to a plane which interects them in three points (*A*, *B*, *C*, Fig. 6) each a different

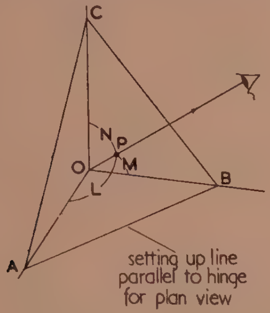


Fig. 6. Geometry of trimetric projection

istance from the origin. The perpendicular to this plane, P, is the direction of viewing. When the drawing has been et up in the semi-scaler for projection, *OP* is the direction f the light beam, *ABC* the plane of the top tray, and the ppropriate co-ordinate plane is the plane of the lower tray.

The drawing has (*a*) to be positioned on the film tray, and) tilted to the correct angle.

(*a*) The positioning is done most easily by finding a line n the drawing that is unchanged in scale, and which must herefore lie parallel to the hinge. This is satisfied by lines B, *BC* or *CA*, depending on whether it is a plan, side or ront view that is being projected on to the plane *ABC*.

If *OP* makes angles *L*, *M*, *N* with the co-ordinate axes (if hey are being chosen, two are free, and the third is found from os$^2 L + \cos^2 M + \cos^2 N = 1$),

hen $OA \cos L = OB \cos M = OC \cos N, (=OP)$

ence angle $OBA = \tan^{-1} (\cos M/\cos L)$

$$OCB = \tan^{-1} (\cos N/\cos M)$$

$$OAC = \tan^{-1} (\cos L/\cos N)$$

Thus the "setting up" line that will have to lie parallel to he hinge can be marked off on the plan or elevation, keeping ig. 6 in mind as a guide.

(*b*) The angle of depression of the lower tray is the inclinaion of the drawing to the plane on to which it is projected, BC. Or the angle between their perpendiculars: *L* for a ide view, *M* for a front view, and *N* for a plan.

Since the tracing table may not be perpendicular to the ght beam, it is best to set up on the reduction ratios, cos *L*, tc., rather than on the interplanar angle. The shadows of he two pairs of fiducial lines with 3 in. separation on the lower ay can conveniently be used here.

It may be shown by spherical trigonometry that the elations between the angles *L*, *M*, *N* and the graduations and ngles on the corresponding trimetric scale are (Fig. 7):

$$\cos Q = \cot M \cot L$$
$$\cos R = \cot N \cot M$$
$$\cos S = \cot L \cot N.$$

If the unit cube has side *k*, and is represented in projection by sides length *a*, *b*, *c*, then from Fig. 6

$$a = k \sin L$$
$$b = k \sin M$$
$$c = K \sin N$$

The value of *k* can be found from the measurements of *a*, *b*, *c* on a given trimetric scale from

$$k^2 = \tfrac{1}{2}(a^2 + b^2 + c^2)$$

and hence *L*, *M* and *N*.

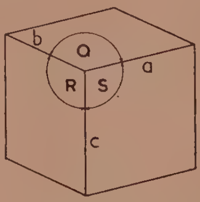


Fig. 7. Cube represented in trimetric projection

Additional uses. Besides the reproportioning of curves and their trimetrical projection, other uses that are suggested for the semi-scaler are:

(*a*) the production of stereographic pairs of pictures of a terrain from its contour map;

(*b*) the production from one curve of another in which each ordinate is a function ($\sqrt{y}$, say) of the original—by using suitably-formed cylinders for the film and for shadow surfaces.

ACCURACY

The effects of mechanical tolerances and beam parallelism have been discussed above. In the prototype these were both refined to the point where they were outweighed by another effect which is irremovable—the spreading of a shadow due to diffraction.

This spreading sets an absolute limit to the definition attainable in the semi-scaler. In the present instrument, on the outer edge of the shadow of a 3 in. wide film at ×2 magnification, distinction becomes difficult between the shadow of lines that are less than 0·02 in. apart.

CONCLUSIONS

The projection of a curve from one plane on to another that is inclined to it, by using light rays in a parallel beam as the "carrier," was found to be capable of sufficient accuracy to be of practical use. It was primarily conceived as a means of changing one scale of an oscillographic record to facilitate its comparison with another. There are other uses for the instrument without any modification, chief of which is the production of trimetric projections from engineers' plan and elevation drawings.

ACKNOWLEDGEMENTS

The author wishes to thank the Chairman of the British Petroleum Co. in whose laboratories this work was carried out, and also particularly Mr. F. Bancroft who made the first experimental model.

REFERENCES

(1) Bainbridge-Bell, L. H. *J. Sci. Instrum.*, **28**, p. 133 (1951).

(2) Boys, C. V. *J. Sci. Instrum.*, **19**, p. 65 (1942).

A new magnetic flux probe*

By Prof. J. E. Parton, Ph.D., M.I.E.E., University of Nottingham, and G. D. Stairmand, M.Sc., Brush Electrical Engineering Co., Ltd., Loughborough, Leicestershire

[*Paper first received* 3 *August, and in final form* 14 *September*, 1955]

A differential-capacity probe designed primarily for investigating magnetic fields in the confined spaces of rotating machines is described; it is suitable for use in fields from 10 mWb m^{-2} (100 G) upwards and will detect both steady and transient fields. In the measuring head of the probe are three parallel members; the applied field causes a deflexion of the earthed, current-carrying middle member. This movement changes the capacitances to earth of the two outer members which form two arms of an a.c. bridge. The out-of-balance voltage caused by these changes in capacitance is, after suitable amplification, indicated on a meter. Experimental characteristics are given for steady and for varying fields. The natural advantages and disadvantages of the probe are discussed.

The traditional methods of measuring magnetic fields employ the coil and fluxmeter or ballistic galvanometer. Most direct-reading practical methods are based on the voltage generated in a coil spinning in the field.(1) More recently the Hall effect in germanium has been used.(2) The possibility of using the magneto-resistance effect in germanium(3) is being explored.

For one or more of a variety of reasons these methods are not suitable for investigating the field distributions around the interpoles of d.c. machines. The probe to be described was developed for this particular purpose.

PRINCIPLES

The measuring head, Fig. 1, consists of a middle conductor of rectangular section and two equidistant, parallel members of semicircular section. The earthed middle conductor carries a known direct current; the two outer members constitute the unearthed plates of two similar capacitors and do not carry current.

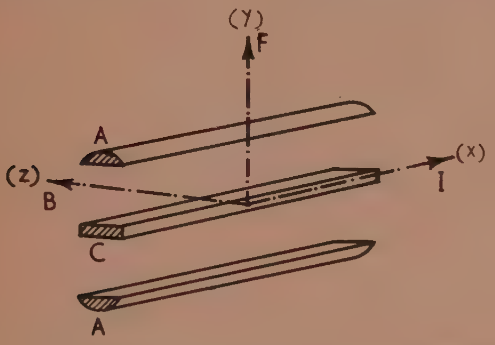


Fig. 1. Diagram illustrating the action of the measuring head of the probe

When the probe is placed with the direct current flowing in the x-direction, and the field B in the z-direction, the middle member of length l between rigid supports, will experience a uniformly distributed load

$$w = BI \quad \text{N/m} \qquad (1)$$

The average deflexion(4) of the middle member will be

$$y = wl^4/720EJ \qquad (2)$$

where E is Young's modulus for the conductor material and J is the moment of inertia of the section about t
z-neutral plane. This becomes

$$y = bIB$$

in which b is a known constant ($l^4/720EJ$). The inner memb
moves an average distance y towards the one plate and
equal distance y away from the other plate, increasing t
one capacitance C' and decreasing the other C''. Ignori
imperfections these capacitors C' and C'' will have the valu

$$\epsilon_r\epsilon_0/A(d-y) \text{ and } \epsilon_r\epsilon_0/A(d+y)$$

in which ϵ_0 is the electric space constant, ϵ_r the permittivi
A the plate area, and d the initial separation.

When connected into the a.c. bridge shown in Fig. 2 t
output voltage will be given by

$$v = V(C'-C'')/2(C'+C'') = Vy/2d$$

Substituting for y this becomes

$$v = (bVI/2d)B$$

from which the output voltage is linearly proportional
flux density B.

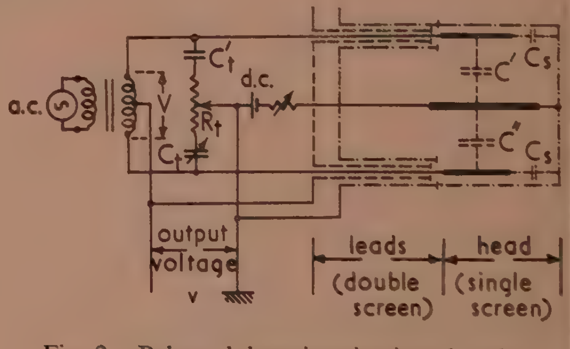


Fig. 2. Balanced detecting circuit and probe

PRACTICAL DETAILS

The bridge was supplied at 500 kc/s *via* a coupling tr
former of low output impedance. The electronic equipn
associated with the detecting bridge [a proximity m
type PM2 (modified) by Fielden Electronics Ltd.] is sh
in block form in Fig. 3.

Trimming and shielding. Owing to slight inequalities
losses it was necessary to put, in parallel with the p
capacitances, a "zero-trimming" circuit consisting

---

* British Patent Application No. 26532/55.

C(25 pF), C_t(0/75 pF) and R_t(0/300 Ω). Prior to any easurements C_t and R_t were adjusted to give no output hen the probe was in zero field.

The loss of sensitivity caused by the shunt capacitances of e leads to the probe was greatly reduced by the use of ouble screens as shown in Fig. 2. An earthed screen was ound spirally round the measuring head to shield it from earby electric fields. The capacitance C_s of the outer embers to this screen was small (10 pF).

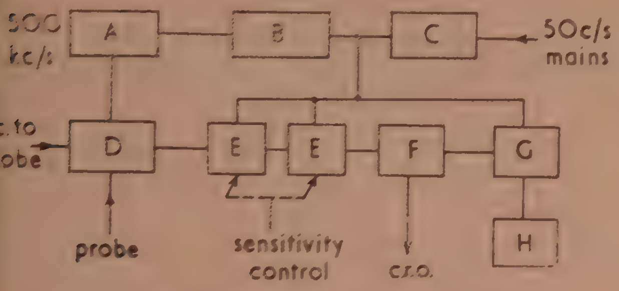


Fig. 3. Block diagram of measuring equipment

A, local oscillator; *B*, voltage regulator; *C*, power pack; *D*, balanced circuit; *E*, tuned amplifier; *F*, first detector; *G*, second detector, *H*, output d.c. (1 mA meter).

The trimming and shield capacitances modify equation (4) o

$$v = \tfrac{1}{2}.V \times \text{fractional change in capacitance}$$
$$= \tfrac{1}{2} V \times (C' - C'')/(C' + C'' + 2C_t + 2C_s)$$
$$= \tfrac{1}{2} Vy/[d + (C_t + C_s).(d^2 - y^2).(\epsilon_r\epsilon_0 A)^{-1}] \qquad (6)$$

s y^2 is negligible compared to d^2 the output D at the meter ecomes

$$D = (\tfrac{1}{2} mV)[d + d^2(C_t + C_s)/(\epsilon_r\epsilon_0 A)]^{-1} \times bIB \qquad (7)$$

here m is the overall amplification of the electronic quipment.

Probe construction. Fig. 4 shows the detailed construction f the measuring head. The assembly shown was held gether by insulated pins, thread and synthetic resin.

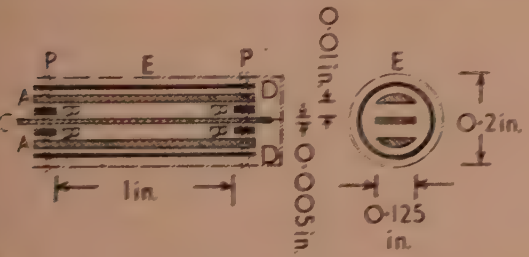


Fig. 4. Construction of the measuring head

A, two outer brass segmental members; *B*, four elephantide insulating pads 0·01 in.; *C*, middle brass conducting member (0·125 × 0·005) in.; *D*, insulating sheath; *E*, earthed screen spirally wound; *F*, insulated pins.

Two specially constructed, small double-screen leads and e stiff insulated copper rod for the direct current were ound with 0·003 in. glass tape and screened. About 6 in. f this lead were dipped in varnish and baked to give a hysically stable connexion for the measuring head. A itably screened box, made of insulating material, terminated the other end for connexion to the d.c. supply and bridge circuit.

PERFORMANCE

Steady fields. The probe and measuring equipment were calibrated with known steady magnetic fields for various direct currents and amplifier sensitivities. Fig. 5 shows three such curves; the form of these agrees with equation (7) for flux densities above 0·02 Wb/m².

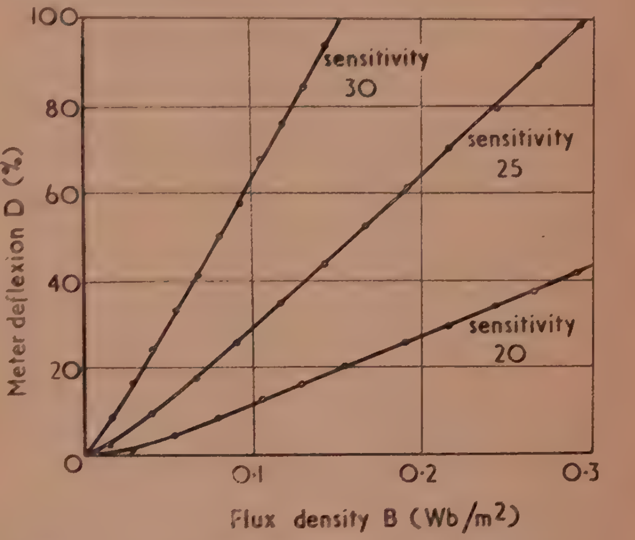


Fig. 5. Overall calibration curves for a 1A direct current in the probe

However, the experimental deflexions were only about 20% of those theoretically predicted by equation (7). For example, in the probe and instrument used, at maximum sensitivity (30 on scale) the relevant quantities were:

$(\frac{1}{2} mV) = 7750$ (measured)
$(C_t + C_s) = 35$ pF
$d = 2{\cdot}54 \times 10^{-4}$ m
$A = 0{\cdot}81 \times 10^{-4}$ m²
$I = 1$ A
$E = 7{\cdot}6 \times 10^{10}$ N/m²
$J = 5{\cdot}4 \times 10^{-16}$ m⁴
$l = 2{\cdot}54 \times 10^{-2}$ m
$b = 14{\cdot}1 \times 10^{-6}$ m²/N

Substituting these quantities in equation (7) gave $D = 32\,BI$. Thus full-scale deflexion ($D = 1$) should occur when flux density B is about 0·03 Wb/m²; whereas, by measurement, a flux density of 0·15 Wb/m² was required as shown in Fig. 5.

The causes for this large discrepancy between theoretical and experimental sensitivities have not been successfully ascertained. Possible sources of error may be (i) neglect of fringing of electric flux, (ii) approximation introduced in capacitance change calculations by taking an average deflexion y rather than performing a strict analysis, (iii) errors in setting up the gaps d(0·01 in.) which are very critical, and (iv) surface irregularities of the plane faces which are probably large compared to the very small deflexions y (of order 0·00002 in.).

According to equation (7), the deflexion should be strictly proportional to the direct current when the probe is in a constant field; this is borne out generally by Fig. 6.

Electronic equipment. This was an adaptation of a commercial unit and was not entirely suitable. For instance, its sensitivity control (0/30 divisions) was not linear, as seen from Fig. 5, and the tendency of its output to drift with time necessitated frequent zero-field adjustments.

Effect of temperature. One attractive feature of the probe is that it should be practically insensitive to normal temperature changes. This was confirmed experimentally; no change in deflexion at any point on the output meter could be found for an increase in ambient temperature from 15 to 70° C, which is the range of interest for d.c. machines on load.

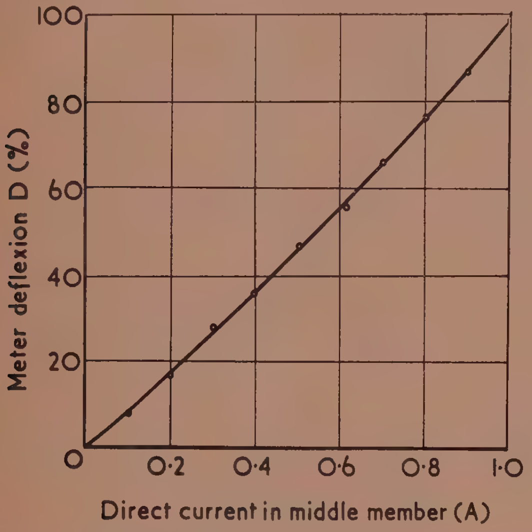


Fig. 6. Effect of current in the middle member: applied field 0·15 Wb/m², sensitivity 30

Direction of magnetic field. Returning to Fig. 1, suppose the field has components B_x, B_y as well as B_z. B_x has no effect on the middle conductor whilst B_y tends to make it move laterally from between the two outer members. As its section modulus is high for such deflexions (625 times the other) its movement is small and there is no observable effect on the capacitance balance. Hence the probe measures only component B_z to which it is also sign-sensitive.

Fig. 7 shows the effect of rotating the probe about the x-axis in a field uniform in the y–z plane. The overall equipment clearly responds to component B_z but the sign-sensitivity has been lost due to the use of modulated carrie in the measuring equipment. Sign-sensitivity could b restored by (i) including a phase-sensitive network or b (ii) off-setting the output meter by deliberately introducin capacitance unbalance with C_t. Some ambiguity of readin is possible if the latter method is used.

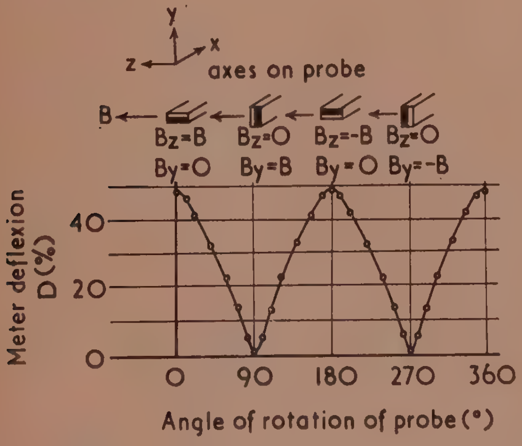


Fig. 7. Deflexion of the meter as the probe is rotated: probe current 1A, field 0·08 Wb/m², sensitivity 30

To get the magnitude and direction of an unknown thre dimensional field, the probe must be successively rotate about the x- and y-axes to obtain maximum reading for B the field direction will then be that of the z-axis of th head.

Varying fields. The natural frequency of vibration of th middle member will impose an upper limit to the frequenc of the a.c. field it is possible to record. Regarding th middle member as a fixed beam, uniformly loaded with i own weight, the natural frequency found from⁽⁴⁾

$$f = (504EJ/w)^{\frac{1}{2}}/2\pi l^2 \quad \text{c/s}$$

becomes roughly 620 c/s. For reasonably linear frequenc response, the probe should only be used up to about 400 c/

Flux transients were photographically recorded for variou conditions.

Fig. 8 shows the record of switching on the d.c. excitatio to an air-gapped iron-cored coil. In this the actual prob output trace (*b*) has been checked by recording the voltag induced in a known coil (*c*) and integrating it by a step-b step process using the 50 c/s timing wave (*a*). The calculate points practically lie on the recorded trace (*b*).

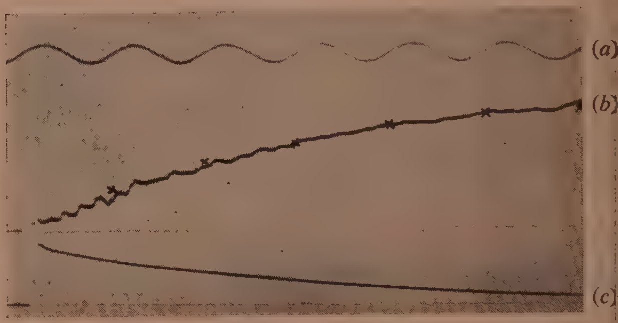


Fig. 8. Flux transient in an air-gapped iron-cored coil

(*a*) 50 c/s timing wave; (*b*) recorded output of the magnetic probe. X = points calculated by integrating (*c*); (*c*) induced-voltage transient.

Of interest on trace (*b*) is the superposed decaying ripple approximately 450 c/s. This is probably the natural frequen of the centre member and is roughly of the same order that expected namely 620 c/s.

COMMENTS

The probe developed has proved reasonably satisfacto for investigating steady-state leakage fields in d.c. machine It should be similarly useful for studying magnetic fields power-frequency machines.

Natural advantages of the probe are: (i) insensitivity normal temperature changes, (ii) linear response to appli flux-density, (iii) the numerous ways in which its sensitivi can be increased, (iv) sensitivity to the direction (or sign) the field, and (v) its reasonably high linear frequency respon (up to about 400 c/s).

Its main disadvantage is that in its present form it is too rge for use in normal air gaps; this applies also to other pes. A smaller probe having a length of 0·5 in., gaps of ·005 in. and an over-all diameter of 0·1 in. is in course of onstruction and likely to be produced commercially. It ill still be too large for machine air gaps, but it will more early indicate the flux density at a point than the present robe does. The present probe, being 1 in. long, does not ithfully respond to the point flux densities in fields, the ensities of which are changing rapidly in space.

The sensitivity of the probe can be most readily changed by ltering the direct current in the middle member. The present robe was designed for a current of 1 A which corresponds a density of 1600 A/in^2. This can be doubled quite safely, articularly for short periods.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the help received from Mr. J. C. M. Sanders of the Brush Electrical Engineering Co., Ltd., who initiated the work, and from Emeritus Professor H. Cotton of the University of Nottingham, who proposed the method.

REFERENCES

(1) Jürgens, B. F. *Philips Techn. Rev.*, **15**, pp. 49–62 (1953).
(2) Pearson, G. L. *Rev. Sci. Instrum.*, **19**, pp. 263–65 (1948).
(3) Pearson, G. L., and Suhl, M. *Phys. Rev.*, **83**, pp. 768–76 (1951).
(4) Morley, A. *Strength of Materials*, 7th ed., pp. 212 and 465 (London: Longmans, Green and Co., 1932).

A microbeam back-reflexion X-ray camera

By D. Lewis, M.Sc., Birkbeck College, University of London

[*Paper first received* 21 *July, and in final form* 25 *August*, 1955]

A direct and accurate optical method of specimen location has been developed to be used with a microbeam back-reflexion X-ray camera. The beams were produced with a fine-focus tube and small pin-holes in platinum foil. Short exposure times were required for Laue and Debye–Scherrer photographs.

microbeam back-reflexion camera has been made to be sed with an Ehrenberg and Spear fine-focus tube(1) which onsiderably reduced the exposure times customary in this pe of work,(2,3) the reduction being obtained by means of e intense X-ray beam and the small dimensions of the hole arrangement. A further advantage was that no ccurately replaceable parts were required in the method of eam location. The camera (Fig. 1) consisted of a brass plate ldered to a wedge-shaped piece of lead, with the wedge gle of 6° to allow the collimator axis to be along the X-ray eam. The collimator consisted of a 10 B.A. screw drilled t along the axis and tipped with platinum foil 0·2 mm ick, through which a fine hole was drilled. Three such llimators were made giving beams of diameter 90, 60 and μ approximately at a working distance of 2 mm from the il. The distance from the X-ray source to the specimen was about 19 mm. A small nut soldered on the collimator served to retain the black paper and film in position, to keep out light and to enable the collimator to be manipulated in the dark-room. The beam was located on a fluorescent activated caesium iodide crystal provided by Dr. Ehrenberg from single crystals made by Dr. J. Franks.(4) The fluorescent image was received, after being reflected by an optically flat mirror, in a travelling microscope fitted with a Newton long working distance (12·8 mm) objective. The microscope was then adjusted to focus the image on to the crosswires, after which the crystal was replaced by the specimen, which was adjusted so that the area to be investigated was also in focus on the crosswires. The mirror was then removed and the exposure made.

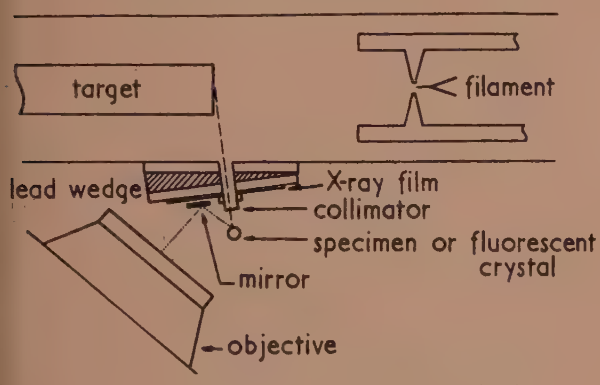


Fig. 1. Layout of camera, tube and objective

To obtain accuracy of specimen location by this method required an objective of high power and consequent short depth of focus. With a ×40 Newton objective a movement of 5 μ along the microscope axis could be detected. The fluorescent spot was first located with a ×3 objective, which was then replaced by the Newton objective. The usual method of focusing a higher power objective could not be used owing to the faintness of the spot and the impossibility of centring the objectives, so a new method had to be devised. The method used was to set the microscope at approximately the correct working distance and then to remove the eyepiece, when a small bright image was seen down the barrel of the microscope near the objective. On racking the microscope through the focusing position the image suddenly became very large, the microscope was then given small lateral motions to increase the intensity of the large image to a maximum. The eyepiece was replaced when the focused image of the spot was found near the centre of the crosswires. Illumination of the crystal showed that the microscope was focused exactly on the crystal surface, and final lateral adjustments brought the image of the spot exactly on the crosswires.

Having located the beam the part of the specimen to be irradiated was brought into focus without any further adjustments to the microscope. To assist in recognizing this part it was found useful to mark the area with a speck of Prussian blue. Experiment showed that the Newton objective was unsuitable for use with a vertical illuminator owing to light scatter up the microscope barrel from the mirrors in the optical system. Local intense illumination was therefore converged on to the area after being reflected by another small mirror. The specimen was mounted on a rigid support capable of giving the necessary motions required to bring it into focus in the microscope, the support being attached on the tube independently of the mirror support and camera. The mirror used to reflect the specimen illumination was attached to a thin lead screen used to protect the film from X-rays scattered from the crystal during adjustments. The microscope used was a specially adapted Baker measuring microscope.

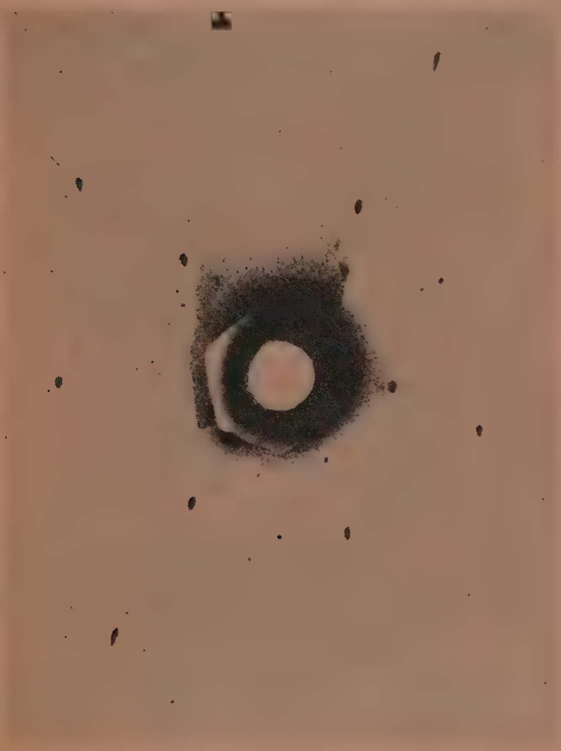


Fig. 2. Laue photograph of aluminium grain, approximately 300 μ diameter, in matrix of similar grains, produced by 90 μ beam (×7)

The accuracy of specimen location was checked using the 90 μ beam by picking up the fluorescent spot under high power and setting it as accurately as possible on the crosswires. The fluorescent crystal was then illuminated with the convergent light and a different selected area on the crystal brought into focus and set accurately on the crosswires without disturbing the microscope. The convergent illumination was then switched off and the fluorescent spot was checked to see that it was on the crosswires and in focus. Owing to crystal roughness and the oblique viewing angle it was usually difficult to make out the exact shape of t rather faint spot but the location was found to be in t middle of the spot to an accuracy of about 20 μ. This cou probably be considerably improved by using a really fi crystal. To test the method Laue photographs were tak from small crystals in polycrystalline pure aluminiu specimens. Corresponding photographs were obtained fro the 90 μ beam in 50 min (Fig. 2), the 60 μ beam in 100 m and the 30 μ beam in 300 min, the tube running at 350 μ and 40 kV. Powder photographs of cold-worked meta gave exposures in about two-thirds of this time (Fig. These times would appear to be less than those of Cah by a factor of more than ten.

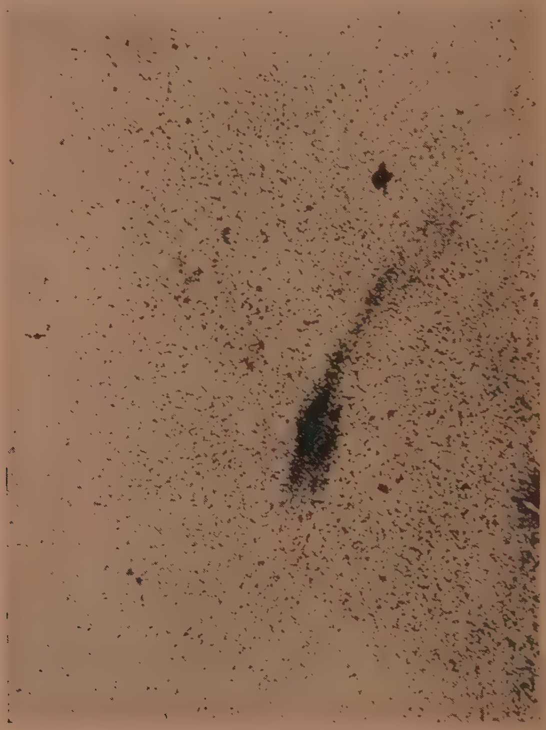


Fig. 3. Part of the 331 ring of cold-worked nickel, copper radiation, produced by the 30 μ beam showin preferred orientation (×36)

ACKNOWLEDGEMENTS

Acknowledgements are due to Professor J. D. Bernal w suggested this paper, to Dr. W. Ehrenberg for many help suggestions, to Dr. J. W. Jeffery for constant interest encouragement, to Johnson Matthey Ltd., Spinneret Depa ment, for drilling the fine holes and to the Birkbeck Coll Research Workshop for design suggestions and construct of the apparatus.

REFERENCES

(1) EHRENBERG, W., and SPEAR, W. E. *Proc. Phys. S* [*London*] *B*, **64**, p. 67 (1951).
(2) CAHN, R. W. *J. Sci. Instrum.*, **30**, p. 201 (1953).
(3) HIRSCH, P. B., and KELLAR, J. N. *Proc. Phys. S* [*London*] *B*, **64**, p. 369 (1951).
(4) FRANKS, J. *Brit. J. Appl. Phys.*, **4**, p. 377 (1953).

Equipment for the vectorial display of alternating voltages in the frequency range 5–215 kc/s

By E. C. Pyatt, B.Sc., A.M.I.E.E., National Physical Laboratory, Teddington, Middlesex

[*Paper received* 4 *August*, 1955]

A sinusoidal alternating voltage is generated and applied to the input of an unknown network; the output voltage of the network is displayed on the Argand diagram reproduced on the screen of a cathode-ray tube. As the frequency is varied the circle diagram of the network is traced on the screen and resonances are indicated by loops in the trace. The frequency range is 5–215 kc/s. There are facilities for frequency calibration; a "dotted line" trace can be produced over a limited frequency range, each dot representing an equal increment in frequency. Circuit details are given. The chief applications of the present design are described—the assessment of electromechanical transducers and as a bridge detector in electromechanical measurements of elastic constants. Numerous electrical circuit applications would also be possible.

simultaneous plot of the amplitude and phase of the output oltage of a network relative to the input voltage, as the requency is varied, gives useful information about the lectrical characteristics of the network. It is convenient to isplay the output voltage vector of the network as a point n the Argand diagram and to reproduce this on the screen f a cathode-ray tube. As the frequency is varied, resonances n the network are indicated by loops in the trace, the fre-uency scale of the loops providing a measure of the corre-ponding Q-values. The apparatus described below was lesigned and constructed by the Ultrasonics Group at the Vational Physical Laboratory, where it has found numerous pplications to measurements on various electromechanical levices.

The present design has a frequency range from 5–215 kc/s. The equipment is rack-mounted on four standard 19 in. anels—(1) power supplies, (2) cathode-ray tube and ssociated circuits, (3) variable oscillator, and (4) fixed scillator, modulators, amplifiers and phase-sensitive de-ectors. The cathode-ray tube is of the compass type, i.e. aving equal X- and Y-sensitivities; the screen diameter is $\frac{1}{2}$ in. and it carries a circular scale of degrees.

Fig. 1 is a block diagram indicating the principle of the nethod. Two outputs of the test frequency are generated at and B with a phase difference of 90°, and these are used as he "carrier frequency" inputs for two identical phase-ensitive detectors. A separate output in phase with one of hem is fed to the network under test. The output from the etwork is fed to the "signal frequency" inputs of both phase-ensitive detectors. The detector outputs are filtered to emove the sum (a.c.) components and only the difference r d.c.) components are left. These have magnitudes proportional to $E \sin \phi$ and $E \cos \phi$, where E is the voltage at the output of the network and ϕ is the phase angle of that voltage relative to the phase of the input. These two d.c. voltages are applied to the Y- and X-plates of the tube respectively, giving the spot a resultant deflexion from the centre proportional to E at an angle with the horizontal of ϕ. The spot thus locates the end of the output voltage vector on the Argand diagram displayed on the tube face, the phase being referred to that at A in Fig. 1.

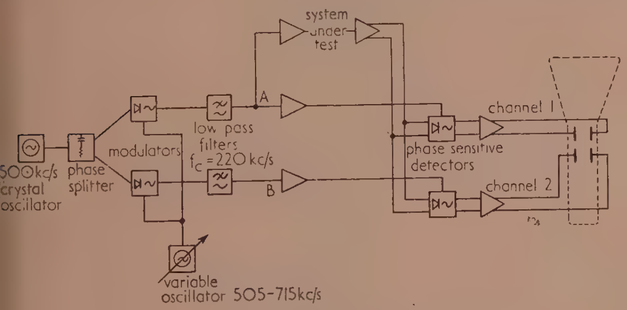


Fig. 1. Block diagram of the circuits

The method of producing two voltages 90° out of phase at the test frequency is shown in Fig. 1. The phase shifting is done at a fixed frequency and the two variable frequency outputs are then produced by modulation. A 500 kc/s crystal-controlled oscillator of conventional type feeds a simple resistance-condenser phase shifter. The two outputs, 90° out of phase, pass to the control grids of two identical suppressor grid modulator stages, using pentode CV 2209. The variable oscillator having a range 505–715 kc/s is connected to the suppressor grids of the modulator pentodes *via* a buffer amplifier. Each modulator stage is matched to a $1\frac{1}{2}$ section low-pass filter by a cathode follower (CV 136). These filters, which have $R_0 = 500\,\Omega$ and $f_c = 220$ kc/s, select the lower sideband 5–215 kc/s and suppress upper sidebands and carrier. Differences between the filters are a likely source of phase shift difference between the channels and it is important therefore to adjust them to be as nearly as possible identical. Each filter output passes *via* a single stage amplifier (CV 138) to the "carrier frequency" terminals of the corresponding phase-sensitive detector.

From one of the filter outputs a voltage is fed to the network under test *via* a cathode follower stage (CV 136). The phase shift in this valve is negligible over the frequency range, so that the phase at the input to the network closely approximates to that at the reference point A (Fig. 1). The maximum voltage obtainable at the network input is 600 mV. The output from the network under test is amplified in a variable-μ stage (CV 454) to provide control of gain and is then fed to a phase splitter, which provides a balanced input for the "signal frequency" terminals of both phase-sensitive detectors. The phase shift in these two stages is also negligible over the frequency range. The phase-sensitive detectors are of the ring type using two vacuum double diodes (CV 140). Controls are provided to balance the input and to suppress the "carrier frequency" in the output. Resistance-capacity circuits are used to filter the output, which is then fed to the grids of the output amplifier valves (two CV 138 pentodes in push-pull). The direct current at the anode is applied to the cathode-ray tube plates. The amplification of the whole system is such that at maximum gain 10 mV at the output of the network under test produce a deflexion of 1 cm on the cathode-ray tube screen. The cathode-ray tube is a compass type (CV 961) with conventional power supplies. An astigmatism control is provided.

Small differences in phase shift between the two channels can cause an error in the final display. These can be minimized by simple equalization as follows. With a 90° phase shift network in the "system under test" position, phase equalization is added to the input amplifier until the output for channel 1 (Fig. 1) is zero. With a zero phase shift network in the "system under test" position, phase equalization is added in the carrier frequency feed to channel 2 until the output from channel 2 (Fig. 1) is zero. As a result the phase angle error over the frequency range falls within ±3°.

The variable oscillator is of the Franklin type (double triode CV 455) and incorporates a means for displaying a frequency calibration on the cathode-ray tube screen during operation. A gearwheel cam having one hundred teeth is carried on the shaft of the incremental tuning condenser, so that, when this is rotated, a miniature switch operates at each tooth. A separate output is derived from the oscillator *via* a cathode follower and fed to the grid of a valve which is switched on and off by the cam-operated switch in its cathode. The output of this valve is connected to the grid of the cathode-ray tube, which is biased beyond cut-off for the normal condition of no input. The electron beam is suppressed therefore until the cam switch operates, when the spot on the screen becomes visible. The resultant "dotted-line" trace enables a frequency calibration to be derived from photographs (see for example Fig. 3); the dot spacing varies from 25 c/s at 5 kc/s to 70 c/s at 215 kc/s.

APPLICATIONS

(*a*) *The assessment of electromechanical transducers*. Circle diagrams of electromechanical transducers can be plotted by displaying the voltage across a small resistance in series w the transducer. The method is particularly valuable in ca where high power is being handled in the transducer a conventional bridge methods can no longer be so ea employed. The drive frequency derived from the equipm may need amplification for some applications and

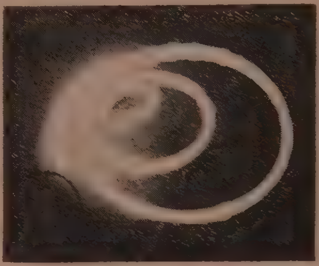


Fig. 2. Circle diagram of barium titanate crystal. Th resonance frequencies are 97·7 kc/s (largest diamete loop), 134·5 kc/s and 170·0 kc/s (smallest diameter loop

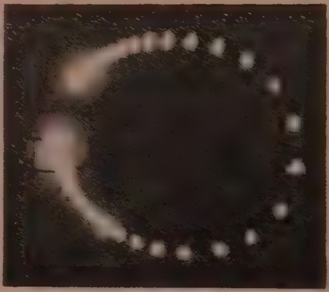


Fig. 3. Portion of circle diagram of barium titanat crystal. Resonance frequency 32·2 kc/s. Dot spacin 33 c/s. Q approximately 100

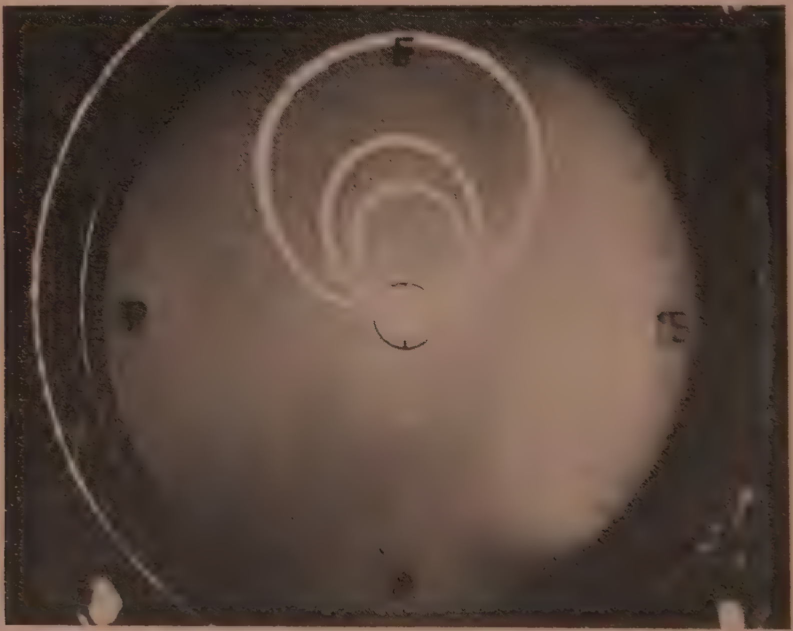


Fig. 4. Circle diagram for three parallel resonance circuits. Resonance frequencies 46·2 kc/s, 100·4 kc/s and 160·4 kc/s

dicated phase will then be the sum of the phase change eing measured and the phase change of the additional nplifiers. If necessary the latter can be measured by placing the network under test by a resistive network. rom the circle diagram, resonance frequencies and cor- sponding Q-values can be deduced by established methods, nd the results used to estimate transducer efficiencies.

Figs. 2 and 3 show some typical measurements on barium anate crystals. The drive voltage is fed to the crystal *via* 1000 Ω resistance. The output is taken across the resistance. he specimen of Fig. 2 exhibits three resonances at 97·7 kc/s, 4·5 kc/s and 170·0 kc/s. Fig. 3 demonstrates the use of e frequency calibration facilities. The resonance frequency 32·2 kc/s and the dot spacing is 33 c/s giving a Q-value ightly in excess of 100.

Useful tests have also been made on other transducer types, cluding ultrasonic cutting tools.

(*b*) *Bridge detector.* Some of the methods of measuring e elastic constants of small metal strips and disks, developed Bradfield and in use at the National Physical Laboratory, volve the detection of mechanical resonances of very small nplitude, which only produce very small impedance changes the external electrical circuits. The vectorial display uipment provides an excellent means for detecting these sonances. The transducer is arranged to form one arm of a shielded bridge, the drive frequency is fed to the bridge in the conventional way and the bridge is balanced approximately at a frequency near the resonance frequency. The vectorial display equipment is connected to the detector terminals of the bridge and the frequency is varied until resonance is indicated by a small loop in the cathode-ray tube trace.

The use of these particular methods of elastic constant measurement has been greatly facilitated by these improved detection arrangements.

(*c*) *Electrical measurements.* Although the equipment was not designed primarily for measurements on purely electrical circuits, it is obvious that a wide variety of such measurements could be made with its aid. Fig. 4 shows a typical circle diagram obtained from three parallel resonance circuits.

ACKNOWLEDGEMENTS

This work has been carried out as part of the research programme of the National Physical Laboratory and this paper is published by permission of the Director of the Laboratory. The author wishes to acknowledge the helpful comments of Mr. G. Bradfield, at whose suggestion the work was done, and of Messrs. H. Pursey and E. P. H. Woodroffe during the course of the development.

Slit drives for single-beam, infra-red spectrometers

By E. L. Blount and A. R. H. Cole, B.Sc., D.Phil., University of Western Australia

[*Paper received* 31 *March*, 1955]

The use of automatic slit drives on single-beam spectrometers is considered and a simple method of making a string slit drive for a calcium fluoride prism is described. The method is applicable to any prism for which the rate of increase of slit opening is not too rapid.

r greatest convenience in the recording of infra-red spectra a single-beam instrument a slit drive is necessary to unteract the approximately exponential fall-off in energy om the source towards long wavelengths. When such a ive is used the operator is not required to watch the strument during a run, and, apart from atmospheric sorption, the final spectrum approximates a double-beam cord requiring very little replotting. With double-beam ectrometers it is possible to use a fraction of the signal om the blank beam to control a servomechanism which aintains that beam at a constant predetermined energy level, t no such signal is available in single-beam instruments. is necessary with these to employ a mechanical system hich may or may not be coupled to the wavelength scanning ive.

Perhaps the best known is that supplied for the sodium loride prism with the Perkin–Elmer model 12C spectro- eter.(1) This consists of a grooved cylinder fitted to the t micrometer and turned by an inelastic string fastened to spiral cam on the wavelength drum. A number of small otors of different speeds for driving the slit micrometer dependently can be supplied by Sir Howard Grubb, rsons and Co. This entails stopping the recording periodically to change the slit drive speed. Cannon(2) has described a variable exponential drive mechanism which, although fairly complicated in construction, can be used for a number of prisms.

The Perkin–Elmer type of string drive has been criticized(2) as being inflexible since it has been made to fit one slit programme for one prism. However, it is the present authors' experience that if most of the spectra measured in each laboratory are recorded by using dilute solutions in such solvents as carbon tetrachloride, carbon disulphide and chloroform, then the slit programme varies little from day to day. Furthermore, it is very simple to change slit drives when changing prisms. The authors feel, therefore, that because of its simplicity and reproducibility the Perkin–Elmer type of drive is the best available for single-beam instruments.

The spectrometer in this laboratory consists of a Grubb–Parsons model S.3.A. monochromator equipped with a Perkin–Elmer thermocouple, light chopper and No. 81 amplifier. This is usually employed with a calcium fluoride prism (single pass) for the range 2·5–7·5 μ (CCl_4 or $CHCl_3$ solutions) and a sodium chloride prism (double pass(3–5)) for the range 7·5–15 μ (CS_2 solutions).

SODIUM CHLORIDE PRISM

Although the Perkin–Elmer drive is designed for the whole range 2·5–15 μ for a single-pass sodium chloride prism, and the number of revolutions of the wavelength and slit drums on the two spectrometers are completely different, by a lucky coincidence it has been found that the Perkin–Elmer drive is admirably suitable for the double-pass sodium chloride system in the Grubb–Parsons spectrometer from 7·5–15 μ under the amplification usually employed here (0·4 μV = full throw). This range is covered in eighteen revolutions of the wavelength drum as is the range 2·5–15 μ on the Perkin–Elmer spectrometer.

CALCIUM FLUORIDE PRISM

The problem arose of constructing a spiral cam and grooved slit drum to suit the calcium fluoride prism in the range 2·5–7·5 μ which is covered in thirty revolutions of the wavelength drum. It is a simple matter to measure the slit width required at the start of each revolution to give a constant throw on the recorder, e.g. 85% full throw. This should preferably be done with an absorption cell in the beam. The differences between successive slit widths in this list are proportional to the length of string which must be wound on to the spiral cam (i.e. its thread circumference) during each turn. Then, after deciding on a suitable diameter for the grooved slit drum (120 mm in this case) and assuming each thread on the cam to be circular instead of spiral, an average diameter for each thread is calculated. The diameter of the string is subtracted giving the diameter required at the bottom of each thread of the spiral cam (see table). The rate of increase of diameter as determined empirically in this
manner is not exactly exponential as required for Cannor
slit drive, but one is able to make allowance for such facto
as prism and solvent absorption.

Thread diameters for the calcium fluoride spiral cam

Thread No.	Diameter (mm)	Thread No.	Diameter (mm)	Thread No.	Diameter (mm)
1	2·0	11	2·5	21	4·3
2	2·0	12	2·65	22	4·6
3	2·0	13	2·8	23	4·9
4	2·0	14	2·9	24	5·1
5	2·0	15	3·0	25	5·4
6	2·0	16	3·1	26	5·7
7	2·2	17	3·3	27	5·8
8	2·3	18	3·5	28	5·8
9	2·4	19	3·8	29	5·9
10	2·4	20	4·0	30	6·0

It is not easy to cut a tapered spiral thread on a simp
lathe, and the authors' method is given in detail in ca
others find it useful. Brass was used for both units of t
mechanism.

It will be seen from the table that, because the rate of s
opening is very slow, one end of the spiral must be rath
thin, and can only be increased in thickness if the size of t
slit drum is increased proportionately. The latter (120 mı
was already as large as conveniently possible. It w
necessary, therefore, to devise a method of cutting the thre
which would eliminate the danger of distorting or breaki
the cam. This was done by using a rapidly rotating den
burr in place of the conventional lathe tool. In this way
was possible to feed the cutting tool into the work at t
beginning of each cut without having the lathe turning.

The thread depth was fixed at $1\frac{1}{2}$ times the string diame
to minimize the possibility of slipping out, and the outsi
diameter taper turned on the lathe in the usual way wi
the narrow end supported by the tailstock. The lathe dri
was then reversed, so that the traverse for the standard rig
hand thread was from left to right. This was done so th
the thread was cut with the cutting tool moving out of t
taper with each cut.

The lathe was set to cut twelve threads to the inch, ar
once engaged, the lathe carriage was not disengaged from t
lead screw, the drive being reversed at the end of each c
with the cutting tool withdrawn. The latter consisted of
No. 8 round dental burr, ground down to a diameter sligh
larger than that of the cord to be used, with the dental d
handpiece jigged up in the lathe tool post in the usual w
With the drill running, the lathe was turned by hand whi
feeding in the burr. It is important that it be turned exac
the same amount each time the burr is fed into the wo
half a turn was found to be satisfactory. No more th
0·002 in. was taken at each cut because of the flexibility
the burr shank, and when it had been fed in to this dep
the lathe was started and the cut continued until the b
left the work due to the taper. When the correct diame
(see table) had been reached at the wide end of the tap
the starting point was moved to the next smaller thread a
the procedure repeated. The slight step resulting from e
"feed-in" was smoothed by hand with a small needle file.

A screw clamp at the narrow end of the taper is used
hold the string. The other end of the string is clamped on
the slit drum, the thread of which (as in the Perkin–Elr
sodium chloride slit drive) must be left-handed. The t
components of the slit drive are held with grub screws on

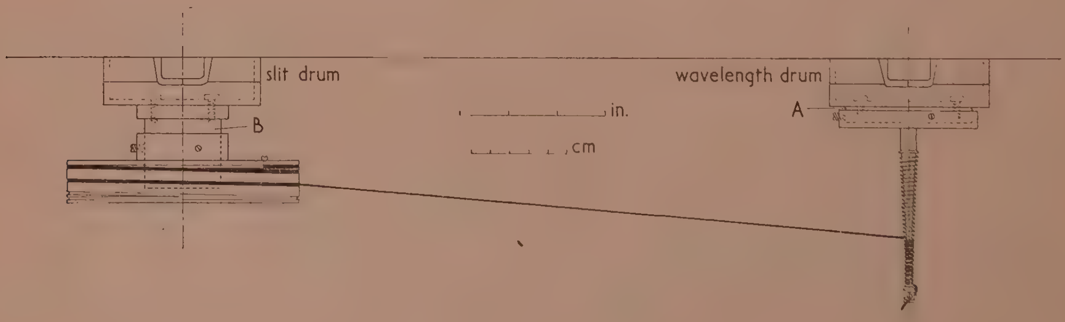


Fig. 1. Details of construction of the slit drive for the calcium fluoride prism

ubes *A* and *B* (Fig. 1) attached respectively to the wavelength nd slit drums of the spectrometer. The diameters of these ubes were chosen to fit the Perkin–Elmer drive for sodium hloride and the collars on the two components of the calcium luoride drive were constructed accordingly.

When prisms are interchanged it is only a matter of two ninutes work to change the slit drives, and the slit widths can ys be reproduced exactly. Fig. 2 compares the spectra ined with and without the automatic drive, with a 1·3 mm of carbon tetrachloride in the beam. Since this is the t suitable solvent for this spectral range the slit drive was osely over-compensated between 5·5 and 7 μ in order to ce the interference caused by the sides of the solvent rption band, and by the atmospheric water vapour rption.

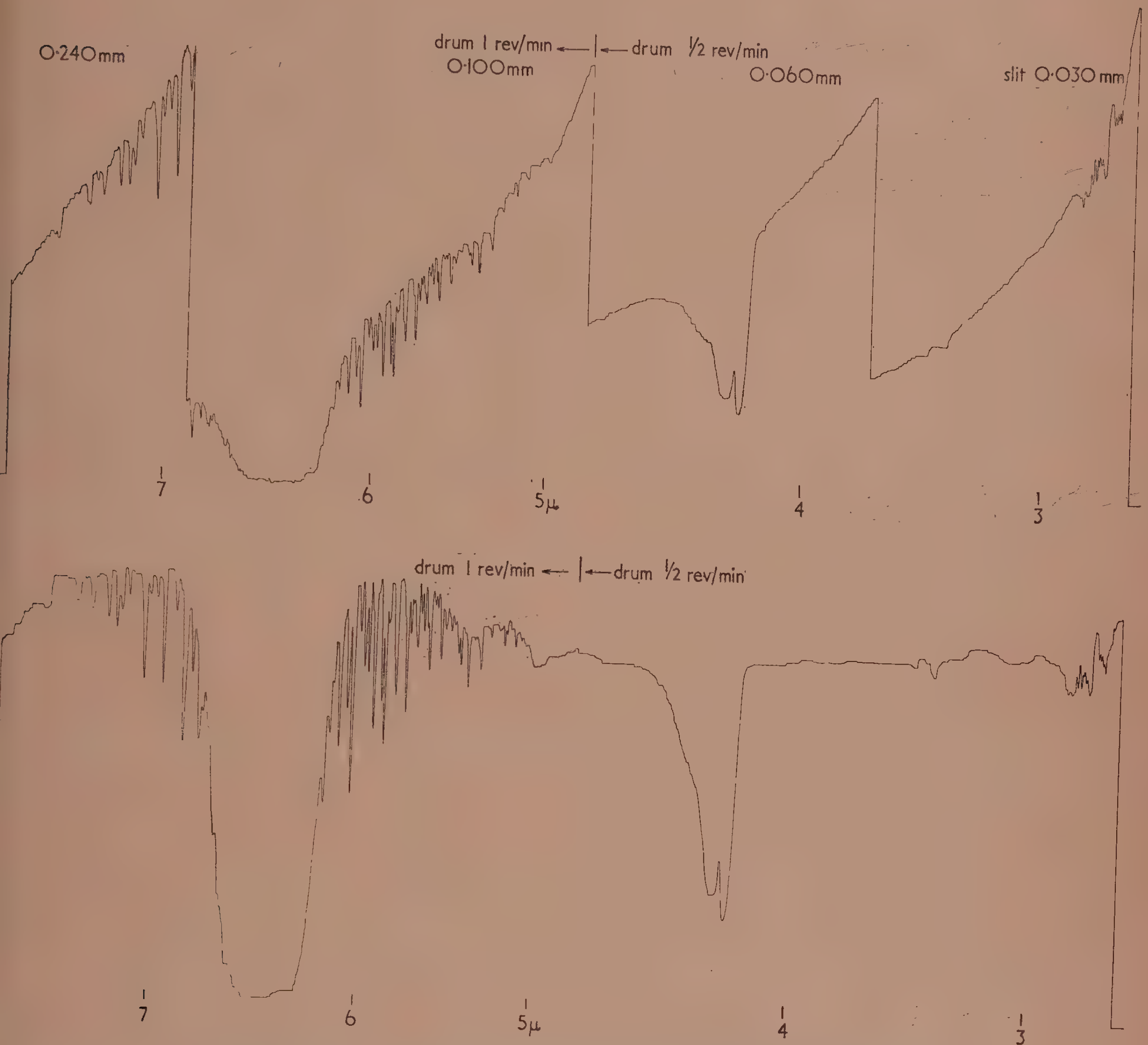


Fig. 2. Infra-red spectrum; 1·3 mm cell containing carbon tetrachloride; calcium fluoride prism

Upper curve, fixed slits; lower curve, slit drive in operation.

ACKNOWLEDGEMENTS

The infra-red spectrometer used in this work was purchased through a generous grant from the Nuffield Foundation, to whom one of us (A. R. H. C.) is also greatly indebted for a Fellowship. The authors also thank Mr. A. Walsh of the Commonwealth Scientific and Industrial Research Organization, Melbourne, for the loan of a Perkin–Elmer slit drive.

REFERENCES

(1) *Perkin–Elmer Instruction Manual*, Model 12C (1949).
(2) Cannon, C. G. *J. Sci. Instrum.*, **29**, p. 50 (1952).
(3) Walsh, A. *Nature* [*London*], **167**, p. 810 (1951).
(4) Rochester, J. C. O., and Martin, A. E. *Nature* [*London*], **168**, p. 785 (1951).
(5) Cole, A. R. H. *J. Opt. Soc. Amer.*, **43**, p. 807 (1953).

An extension of Noar's method of calibrating plates for spectrophotometry

By A. H. Gabriel, B.Sc., and D. W. O. Heddle, Ph.D., Department of Physics, University College, London

[*Paper first received* 11 *August, and in final form* 2 *September*, 1955]

A method of heterochromatic interpolation of emulsion calibration data is described. The method makes use of the co-ordinates of the calibration cross-over points on the Noar nomogram. The physical significance of these co-ordinates is discussed in an Appendix.

Noar (Ref. 1, p. 64) has developed a mathematical relationship between photographic blackening and exposure which can be shown to be applicable to very high-speed panchromatic emulsions. A later paper (Ref. 1, p. 99) describes a nomogram chart which reduces considerably the work involved in spectrophotometry at any wavelength. In many experiments, however, it is not practicable to record a sufficient number of calibration spectra for each wavelength at which intensity ratios have to be determined. This paper describes a method of interpolation which enables such intensity ratios to be found, and may also improve the accuracy of photometry at wavelengths where more complete calibration data are available. Spectra of the source of unknown intensity and of a calibration lamp are photographed alternately, one exposure time being used throughout. The intensity in both cases is reduced by a rotating step-sector which transmits in the ratios 16 : 4 : 1. The developed plate is then photometered and calibration lines are drawn on the nomogram chart connecting microphotometer readings which correspond to an intensity ratio of 4 : 1. A "characteristic line" is then drawn through the cross-over point and the origin. The co-ordinates of the cross-over point [log (intensity ratio) $= x$, angle between characteristic line and vertical $= \alpha$] are noted. Fig. 1 shows a schematic

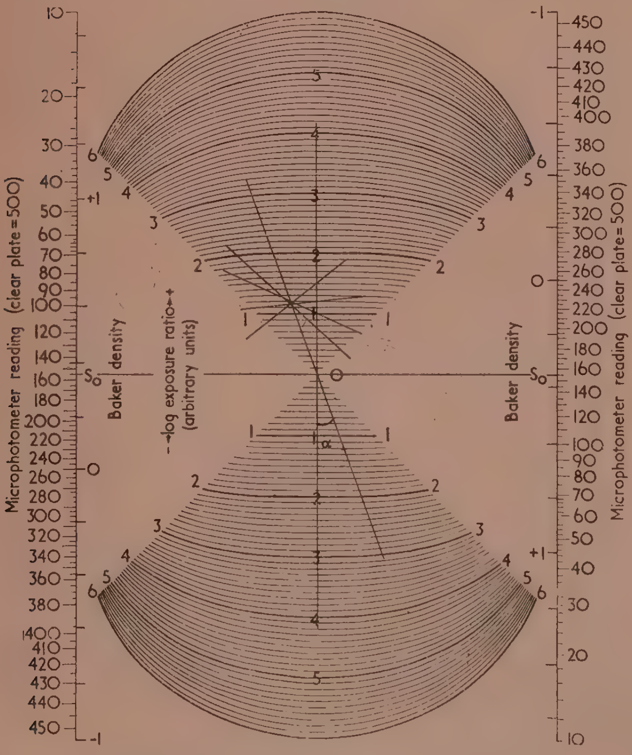


Fig. 1. Nomogram chart of the type used

intersection, giving $x = 1\cdot17$ and $\alpha = -18\cdot3°$. A lin
scale of Baker density, $S = \log\left[(1/T) - 1\right]$, is also mark
on this nomogram. Values of x and α are then found
each wavelength for which calibration data are available.
certain cases it may be possible to find one of the co-ordina
much more accurately than the other. If, for example,
calibration lines were all nearly horizontal, then a reasona
value of x would be obtained yet there might be little indicati
of the value of α. It should be noted that calibration d
are obtainable from either the known or unknown spect
The necessary condition is that intensity ratios of 4
should give blackenings corresponding to microphotome
readings of between 10 and 450. If all three intensity st
of each spectrum are in this class then a good cross-o
point will be obtained. In practice this is only the case if
two spectra are of nearly equal intensity and if the exposi
time is suitably chosen. In general this is not the case a
the accuracy of the cross-over point is reduced.

The values of x and α found as described above are th
plotted against wavelength and smooth curves are dra
through the experimental points (Fig. 2). Some indicati
of the behaviour of the curves in regions where there
few points can be found from other experiments with
same emulsion and developer and from considerations of
physical significance of the co-ordinates. Values of x an
can now be read from the curves and characteristic lines
each wavelength drawn on the nomogram chart. At w
lengths where a point has been found from a "good" cr
over (one with all three steps of each spectrum usable)
gain in accuracy by this procedure will be not more

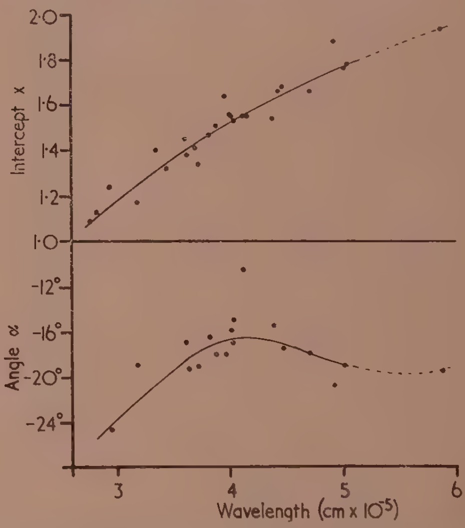


Fig. 2. Typical curves showing the variation of th
co-ordinates of the cross-over point with wavelength

)%, but as the accuracy of the cross-over is reduced so the in in accuracy will increase until, at wavelengths where ly one intensity step of each spectrum is usable and no cross-er point at all can be obtained, the accuracy is increased om zero to a value comparable with that of neighbouring avelengths.

The method of computing relative intensities is now raightforward and is based on the assumption that microhotometer readings in the region of 150 to 200 give the most nsitive measurements of intensity. There are two principal asons for this. The corresponding densities lie on the steep gion of the H and D curve, and are close to the optimum lue for accurate microphotometric measurement. One ectrum, not necessarily the same for each wavelength, is ow chosen as the unit of intensity, such that all three transission steps are usable, i.e. giving readings between 10 and 50. In general, one such step will be in the region 150 to 00 and this is taken as correct. The other two readings are en modified so that the readings are consistent with the lues of x and α found from Fig. 2. All three readings are ow equally valid. The best reading for each other spectrum hat which is in the region 150 to 200) is now compared with e corresponding step of the first spectrum. This comarison is made in precisely the manner described by Noar: e corresponding readings are joined and the intercept on e characteristic line is read. Let this be y. Then

$$(\log I_1/I_2)/\log 4 = y/x \qquad (1)$$

his calculation is a simple operation on a log–log slide rule.

Although this method of photometry may appear to be omewhat lengthy, it is, in fact, hardly more so than the irect computation of each wavelength separately, and in y case the time spent in computation is short compared ith that of taking readings on a non-recording microhotometer.

ACKNOWLEDGEMENTS

The authors are indebted to the Shell Refining and Marketg Co. Ltd. and Dr. J. Noar for a supply of nomogram arts. One of us (A. H. G.) wishes to acknowledge the ceipt of a maintenance grant from the Department of cientific and Industrial Research.

APPENDIX

he physical significance of the co-ordinates x and α

From Noar's equations

$$S = S_m + AE^B \qquad (2)$$

$$(S_1 - S_m)/(S_2 - S_m) = (E_1/E_2)^B \qquad (3)$$

is clear that

$$x \propto B \qquad (4)$$

nd

$$\cot \alpha \propto S_0 - S_m \qquad (5)$$

e constants of proportionality being dimensions of the omogram.

For a constant value of α, and therefore of S_m, a change x corresponds to a change of the (log E) scale of the H nd D curve, and under these conditions x is proportional to , the slope of the H and D curve.

Fig. 3 shows a family of H and D curves calculated from quation (3) with a constant value of $B(x)$ and different alues of $S_m(\alpha)$. Their relative position on the (log E) axis is quite arbitrary. The curves show a strong resemblance to those for emulsions of different grain sizes but otherwise similar characteristics (Ref. 2, p. 177). As, for any one emulsion, α varies with wavelength, this could be interpreted as showing that different classes of grain are sensitive to different wavelengths. The resemblance may, however, be fortuitous as the different spectral absorptivities of the emulsion constituents could lead to a similar family of curves.

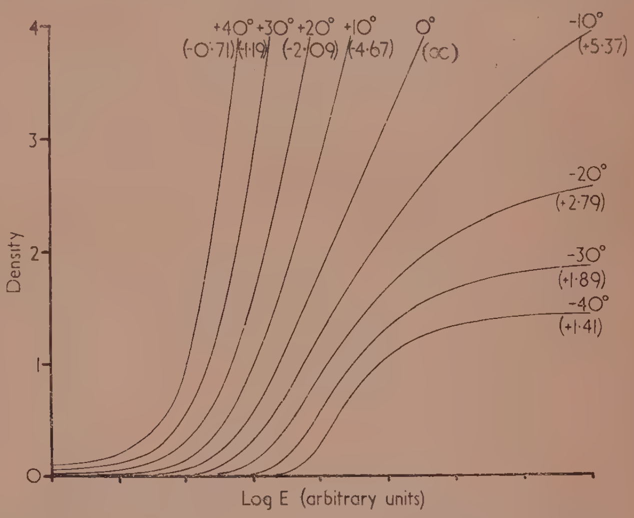


Fig. 3. H and D curves corresponding to various values of α, with $x = 1$. Values of α and S_m (in brackets) are shown on each curve

The maximum density, D_m, attainable at any wavelength, will depend on the fraction of grains sensitive to that wavelength, and the relative sensitivity of the emulsion at different wavelengths will thus be indicated by the value of D_m. At densities greater than unity, the limiting density is very nearly equal to S_m and from equation (5) we would therefore expect ($-\cot \alpha$) to be a measure of the relative sensitivity of the emulsion at different wavelengths. The data of Fig. 2 have been used to prepare Fig. 4 which shows the variation of cot α with wavelength. The broken line represents the sensitivity of an unspecified panchromatic emulsion quoted by Mees (Ref. 2, p. 853).

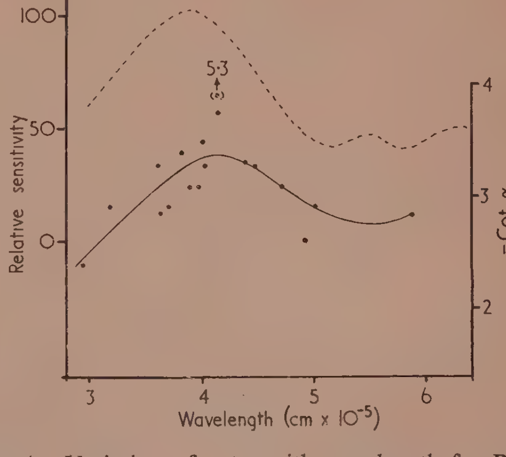


Fig. 4. Variation of cot α with wavelength for P.2000 emulsion (————). Relative sensitivity of panchromatic emulsion (------)

It is also apparent from Fig. 3 that γ varies with α and so the graph of x against wavelength in Fig. 2 is not expected to indicate the variation of γ with wavelength. It is possible that the variation of γ with wavelength may be deduced from values of x and α but there would be little value in doing this precisely, as it is clear that γ will vary somewhat more slowly than x/α.

The analysis of the previous paragraphs is, of course, true only for negative values of α for it is only for these values that a maximum limiting density is indicated by the Noar equations. For positive values of α the Noar equations lead to a minimum value of limiting density. If we assume, as have other workers (Ref. 2, Chapter V), that a certain minimum number of quanta are required before an image becomes developable then it appears that the sensitivity the emulsion increases as α decreases.

The authors have not investigated the behaviour emulsions with positive values of α as they are primari interested in the use of high-speed panchromatic emulsio and, in general, these exhibit negative values of α as o would expect from comparison of Fig. 3 with H and curves published in photographic data books.

REFERENCES

(1) Noar, J. *Photogr. J.*, **91B**, pp. 64, 99 (1951).
(2) Mees, C. E. K. *The Theory of the Photographic Proce* (New York: The MacMillan Co., 1954).

The measurement of specimen temperature in a high temperatur X-ray powder camera

By R. S. Pease, M.A., Atomic Energy Research Establishment, Harwell, Berks.

[*Paper received* 3 *August*, 1955]

Errors of specimen temperature measurement by means of thermocouples placed near the specimen are examined theoretically and experimentally for the case of an evacuated Unicam camera, where the furnace arrangements can be regarded as an imperfect radiation bath. Errors which increase monotonically with temperature arise because the radiation temperature of the furnace is not everywhere the same. Errors which are of opposite sign, and which increase to a maximum at about 200° C and then decrease with increasing temperature, arise because of conduction down the thermocouple leads. Design requirements to minimize the errors and keep them constant from one specimen to another are given.

A difficulty frequently encountered with high temperature X-ray powder cameras is the accurate measurement of specimen temperature in cases where it is not possible to mix with the specimen a substance of known thermal expansion. In these cases it is usual to measure the specimen temperature by one or two thermocouples placed near the two ends of the cylindrical specimen. It is important to know why and by how much the temperature differs from that of the specimen, so that the difference can be minimized and the calibration kept constant from one specimen to another. The present paper reports theoretical and practical work on this problem, which, though related to a specific Unicam 19 cm camera, is generally applicable in cases where the heat is transferred to the specimen and thermocouples mainly by radiation.

With radiant transfer of heat, the temperature differences are, of course, zero if the specimen and thermocouples are isolated objects entirely surrounded by furnace walls at a uniform temperature; but such perfection cannot normally be achieved in practice. The consequent errors can be divided into two classes:

(*a*) *geometric errors*, which arise because the surfaces surrounding the specimen and thermocouples are not everywhere at the same temperature;

(*b*) *conductive errors*, which arise because there is some transfer of heat along the thermocouple leads, along the specimen support, and in the residual gas in the camera.

These two classes of error are discussed theoretically in the first sections. The observations reported in subsequent sections are shown to be in accord with main theoretic predictions.

GEOMETRIC ERRORS

The furnace arrangement of the camera used is shown Fig. 1. The principal geometrical imperfection is the g between the two halves of the furnace, through which t

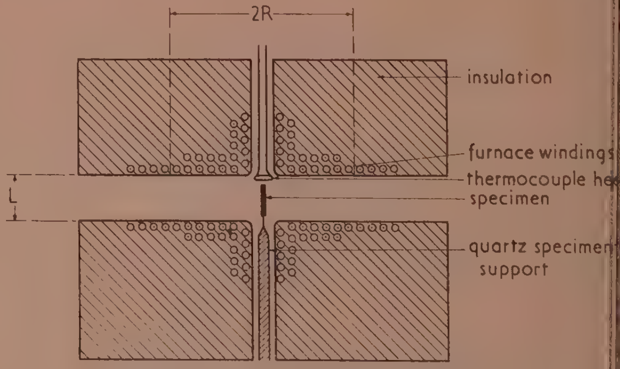


Fig. 1. Sketch of furnace arrangement

specimen has a view of surfaces at the laboratory temperat T_0. To a first approximation, we shall consider the furn walls surrounding the specimen as being at a unifo temperature T_w. These walls are diffuse reflectors and much larger surface area than the specimen surface area.

JOURNAL OF SCIENTIFIC INSTRUMENTS

A MONTHLY PUBLICATION
DEALING WITH THE PRINCIPLES,
CONSTRUCTION AND USE OF SCIENTIFIC INSTRUMENTS

Produced by The Institute of Physics
with the co-operation of the National Physical Laboratory

EDITOR
H. R. LANG
A.R.C.S., PH.D., F.INST.P.
Secretary of The Institute of Physics

VOLUME 32

LONDON
THE INSTITUTE OF PHYSICS

nat the presence of a specimen is assumed to have only a egligible influence on the temperature distribution. Let the olid angles subtended at the specimen by the furnace and iboratory surfaces be $4\pi(1-\omega)$ and $4\pi\omega$ respectively. Then the temperature T_s of an isolated specimen is given by ne equation of radiation balance:

$$T_s^4 = (1-\omega)T_w^4 + \omega T_0^4 \tag{1}$$

hich can be simplified without serious error for small ω) give

$$T_w - T_s = \tfrac{1}{4}\omega T_w[1-(T_0^4/T_w^4)] \tag{2}$$

he furnace walls consist essentially of coaxial disks of adius R, separated by the gap L, so that to a first approxiation $\omega = L/2R$. In the camera used L was 0·75 cm, and can be taken as the radius of glowing surfaces at about 00° C, which was about 2 cm, so that ω in this case is bout 0·2.

Thus the effect of the furnace gap is to produce a difference etween the temperature of the furnace walls and that of the pecimen which increases as the absolute temperature in the ange of practical interest, and which is about 50 at 1000° K. may be noted that the emissivity and exact dimensions of ne specimen are immaterial to this difference on account of irchhoff's radiation law.

The variation of radiation temperature along the axis of ne camera depends on the variation of ω along this axis. Vithin the furnace gap at a distance of x from the midpoint f the furnace gap, ω is given to a second approximation by ne expression

$$\omega = (L/2R) - (L^3/16R^3) - (3Lx^2/4R^3) \tag{3}$$

Vith the values of L and R adopted above, terms involving igher powers of L/R are small, so that ω varies across the ap in a parabolic fashion with a maximum (and hence a emperature minimum) at the centre. Using the above alues of L and R, the difference between the temperature at ne centre and that at a point flush with the furnace walls is nus estimated to be 3 at 1000° K. Hence the temperature radients arising in this way are not likely to be large, but ney cannot be altogether neglected, especially as this parcular estimate is exceptionally rough owing to its dependence n R^3.

A much larger difference of ω exists between the value in ne furnace gap and that in the axial cavities. These cavities re relatively narrow holes which are normally at least artially blocked by insulators for the thermocouple leads, r by the specimen support. Objects within them are thus rgely surrounded by furnace walls, and cannot "see" the iboratory surfaces through the gap. Consequently the idiation temperature within the cavities must exceed that ithin the gap by approximately the value given by equation), that is $0{\cdot}05T_w$. Evidently a serious error will arise if ne thermocouple head is effectively within the axial cavity, hile the specimen scattering the X-rays is within the gap.

The temperature gradient within the gap will be modified the upper and lower halves of the furnace are running at fferent power levels. Let the powers flowing through eating surfaces of the two halves be P_1 and P_2 per unit nitting surface respectively. The corresponding wall mperatures T_1 and T_2 are then given by the simultaneous quations:

$$\begin{aligned} T_1^4 &= (P_1/\xi) + 2\omega T_0^4 + (1-2\omega)T_2^4 \\ T_2^4 &= (P_2/\xi) + 2\omega T_0^4 + (1-2\omega)T_1^4 \end{aligned} \tag{4}$$

where ξ is the Stefan–Boltzmann constant. Small objects placed flush with the walls will take up temperatures τ_1 and τ_2 determined by the further equations:

$$\begin{aligned} \tau_1^4 &= \tfrac{1}{2}T_1^4 + (\tfrac{1}{2}-\omega)T_2^4 + \omega T_0^4 \\ \tau_2^4 &= \tfrac{1}{2}T_2^4 + (\tfrac{1}{2}-\omega)T_1^4 + \omega T_0^4 \end{aligned} \tag{5}$$

An approximate solution of these equations is

$$\tau_1 - \tau_2 = \tfrac{1}{2}\tau_m\left(\frac{\omega}{1-\omega}\right)^2\left(\frac{P_1-P_2}{P_1+P_2}\right)\left(1-\frac{T_0^4}{\tau_m^4}\right) \tag{6}$$

where $2\tau_m^4 = \tau_1^4 + \tau_2^4$.

This expression has two important features. First, provided the ratio P_1/P_2 remains constant, the variation of $\tau_1 - \tau_2$ with temperature is of very much the same form as the error given by equations (2) and (3). Secondly, provided P_1/P_2 is approximately equal to unity, no large errors are introduced: for example, if $P_1/P_2 = 1{\cdot}1$, then $\tau_1 - \tau_2$ is about 1·5 at 1000° K.

Since the geometric imperfections of the furnace arrangements can usually be described in terms of an analysis either like that leading to equation (2) or like that leading to equation (6), these results suggest that geometric errors always increase with temperature and can usefully be described by the expression

$$\Delta T_1 = K_1 T_s[1-(T_0^4/T_s^4)] \tag{7}$$

where K_1 is a factor depending on the geometrical imperfections. With the particular camera used, and with the reference thermocouples in the normal position in the furnace gap, nearly flush with the top and bottom surfaces, equation (3) shows that the sign of ΔT_1 is such that the thermocouples give too high a value.

CONDUCTIVE ERRORS

Any object placed in the furnace will lose or gain heat by conduction along its supports or other attachments. This heat flow is counterbalanced by a radiative flow of heat through the surfaces of the object. Conduction effects are particularly serious in the case of the thermocouples, and these will be considered in detail first.

Conductive errors in the thermocouple. The thermocouples are normally supported only by their leads. Let A, ε and T_j be the surface area, emissivity and temperature of the head of the thermocouple; let r, σ and $(dT/dx)_j$ be the radius, conductivity and temperature gradient of the lead at the point at which it joins the head. Then T_j is related to the effective radiation temperature T_s of the furnace by the equation

$$\sigma\pi r^2(dT/dx)_j = A\varepsilon\xi(T_s^4 - T_j^4) \tag{8}$$

where ξ is the Stefan–Boltzmann constant. With $T_s \simeq T_j$, a convenient approximation is

$$\Delta T_2 = T_s - T_j = (\pi r^2\sigma/4A\varepsilon\xi T_j^3)(dT/dx)_j \text{ degrees per lead} \tag{9}$$

A tractable expression for $(dT/dx)_j$ can only be obtained after rather drastic simplification of the physical situation. As a start, one may assume that all the heat flow is from the thermocouple head down a lead of length L_0 to a heat reservoir at temperature T_0, so that

$$dT/dx = (T_j - T_0)/L_0 \tag{10}$$

When substituted in equation (9) this expression gives an error which rises with temperature initially as $(T_j - T_0)$, reaches a maximum at $1\cdot5T_0$, and decreases as T_j^{-2} at high temperatures. It is usually erroneous, however, to identify L_0 with the length of lead to the terminals in the vacuum chamber; for the temperature of the lead outside the furnace is governed by the radiation loss equation

$$d^2T/dx^2 = (2\epsilon\xi/\sigma r)(T^4 - T_0^4) \qquad (11)$$

If the lead is sufficiently long, dT/dx is negligible when $T = T_0$, so that

$$dT/dx = (4\epsilon\xi/5\sigma r)^{\frac{1}{2}}(T^5 - 5TT_0^4 + 4T_0^5)^{\frac{1}{2}} \qquad (12)$$

Using constants appropriate to 0·005 in. diameter platinum wire leads of length 15 cm, the values of dT/dx obtained from equation (12) are so much larger than those obtained from equation (10) that it is evident that conduction to the terminals is a small effect.

Under this circumstance, the substitution of equation (12) in equation (9), with $T = T_j$ provides the *maximum* possible thermal gradient in the lead at the junction with the head, and corresponds to a physical situation in which only the head of the thermocouple is in the furnace, and the leads are entirely surrounded by surfaces at T_0. In this case there is again a rapid rise of error with temperature, a maximum at $1\cdot87T_0$, and a high temperature decrease of error as $T_j^{-\frac{1}{2}}$.

To obtain a tolerably realistic model of the actual arrangement, it will be supposed that the lead can be divided into two parts: that part which is outside the furnace, and surrounded by surfaces at T_0; and that part of length l which is inside the furnace. Outside the furnace the gradients are given by equation (12); inside they are governed by the equation

$$(dT/dx)^2 = (4\epsilon\xi/5\sigma r)(T^5 - 5TT_s^4 + B) \qquad (13)$$

where B is an integration constant. At the head of the thermocouple, where $T = T_j$, we may put $(5\sigma r/4\epsilon\xi)(dT/dx)_j^2 = \eta$, and thus $B = 5T_jT_s^4 - T_j^5 + \eta$. At the point where the lead passes out of the furnace, the temperature gradients given by equations (13) and (12) must be equal. The temperature T_Q at this point is thus given by

$$T_Q = (B - 4T_0^5)/5(T_s^4 - T_0^4) \qquad (14)$$

so that the mean gradient in that part of the lead in the furnace is

$$(T_j - T_Q)/l = (T_j^5 + 4T_0^5 - 5T_jT_0^4 - \eta)/5l(T_s^4 - T_0^4) \qquad (15a)$$

$$\simeq T_j/5l \text{ for } T_j \simeq T_s > 2T_0, \text{ and } \eta \text{ small} \qquad (15b)$$

$$\simeq (T_j - T_0)/2l, \text{ for } T_j \simeq T_s \simeq T_0, \text{ and } \eta \text{ small} \qquad (15c)$$

Because $T_j < T_s$ and $\eta > 0$, the values of the mean gradient given by equations (15*b*, *c*) are overestimates; moreover, the mean gradient is itself an overestimate for $(dT/dx)_j$, as can be seen from equation (13). Hence the approximations (15*b*, *c*) can safely be used to provide upper limits for $(dT/dx)_j$, although in cases where l is small, η cannot be neglected, and these expressions may give bigger values of the gradient than equation (12). Equation (15*a*) reduces to equation (12) for large values of η.

We may discuss these results in terms of equation (10) which gives a conductive error ΔT_2

$$\Delta T_2 = K_2(T_j - T_0)/T_j^3 \qquad (16)$$

and $K_2 = \pi r^2\sigma/4A\varepsilon\xi L_0$. Unless the leads are unusually short L_0 is not their physical length, but is an effective length depending on the temperature. If the length of lead in t furnace is very short, then L_0 decreases with temperatur and its value depends on σ, ε and r. With an appreciab length of lead in the furnace, the approximations (15) sugge that for small η, L_0 depends mainly on l and is constant high temperatures. But in either case, the main qualitati features of equation (16) are maintained with a rapid increa of error to a maximum in the region of 500° K, followed by steady decrease, at a rate which is somewhere between T and $T^{-\frac{1}{2}}$. It should be noted that ΔT_2 can be very lar unless precautions are taken. Thus at 1000° K, wi $(dT/dx)_j = 50$°K/cm, thermocouples which have an unblacken head of area 0·5 cm² and 0·020 in. diameter leads, will gi an error of the order of 70°K.

Conduction in the specimen. Calculations similar to tho given for the thermocouples, can be applied to the specime In this case, however, to maintain a constant calibration fro one specimen to the next it is vital that conduction to t specimen shall always be negligible. If not, the calibrati of the error of the thermocouple measurements will vary n only with the emissivity of the specimen (as has been fou by Berry, Henry and Raynor(1)) but also with the lengt radius and thermal conductivity of the specimen and specime support. For this purpose an order of magnitude calculati is sufficient.

With the normal arrangement the main specimen suppo is a rod of silica in the axial cavity extending nearly up the furnace gap. Silica is so poor a conductor that the t of the holder is near to the radiation temperature of t cavity. Consequently the temperature difference between t support and that part of the specimen irradiated by X-ra (assuming a perfect insulator) is given by equation (2), an as shown above, is about $0\cdot05T_s$. Without effective insulatio this difference will heat the specimen. An elementary ca culation shows, for instance, that if the specimen is mount on a length of fused silica about 0·1 mm in diameter a 2 mm long, so that the specimen itself is solely within t furnace gap, then a cylindrical specimen of normal si (0·5 cm × 0·5 mm diameter) will not rise in temperature more than 1 at 500° K. For reasons similar to tho applicable in the case of the thermocouple conduction erro the error is a maximum at about 500° K, and thereaf decreases with increasing temperature.

Conduction in the gas. The quantity of heat Q transferr by air at a pressure P cm of mercury, between two surfac differing in temperature by ΔT, can be estimated from t formula(2)

$$Q = 0\cdot8T^{-\frac{1}{2}}\Delta TP \text{ cal s}^{-1} \text{ cm}^{-2}, \text{ at low pressures.}$$

In the present application ΔT is determined by the ge metrical imperfections of the furnace as about $0\cdot05T$. Co ductive errors can usually be reduced well below this figu and will thus be neglected in these considerations.

Thus if the maximum allowable alterations to the tempe ture differences is taken as 1° C, the maximum allowa pressure is determined by the equation

$$4\xi T^3 = 4\cdot2 \times 10^{-2}\sqrt{T}P_{\max}$$

i.e. $$P_{\max} = 1\cdot3 \times 10^{-10}T^{5/2} \text{ cm of mercury} \qquad ($$

$P_{\max}$ thus depends on temperature; numerical values 40 μ at 1000° K, and 6 μ at 500° K. The emissivity a accommodation coefficient of the surface have been taken unity. The maximum pressures given by equation (17) likely to be smaller than required in practice, since t first approximation both thermocouple and specimen e affected equally by the gas conduction. When the pressure ses to a value where the mean free path is small compared o the dimensions of the furnace gap, the fact that the ermocouples are much nearer than the specimen to the rnace walls will then produce an appreciable error.

OBSERVATIONS

Observations were taken while calibrating a Unicam amera with a furnace arrangement of the type shown in ig. 1. Platinum/platinum-rhodium thermocouples were sed throughout. The reference thermocouple consisted of 4 mm diameter ring of 0·020 in. diameter wire, with leads f 0·005 in. diameter wire. The ring head was placed on the xis of the furnace, just clear of the axial cavity of the upper alf of the furnace. The head area, which was not blackened, as estimated as 0·3 cm^2, and the effective length of the eads in the furnace was about 3 cm. The currents in the wo halves of the furnace were kept equal to each other at ll temperatures. The camera was evacuated to a pressure f about 5 μ.

The reference couple was calibrated by placing in the pecimen position a thermocouple constructed with 0·001 in. iameter leads and a large head area to have negligible onductive error on the basis of equations (9) and (15). This pecimen thermocouple head, which consisted of a small lackened coil of 0·020 in. diameter wire, was supported on thin spike of silica drawn out from the main specimen upport. The calibration was carried out by observing the emperature recorded by each thermocouple, after the furnaces ad been allowed to settle down over a period of several ours. Electromotive forces were measured on a precision otentiometer, taking all the precautions normally associated ith this type of work. The calibration points obtained are resented at Fig. 2. Curve *A* is a smooth curve drawn rough the observed points; curve *B* is a curve of the form

$$\Delta T = [K_2(T - T_0)/T^3] - K_1 T[1 - (T_0^4/T^4)]$$

tted to the observed points.

It will be seen that the main theoretical predictions are orne out. The error increases rapidly in the region 0–150° C nd reaches a maximum in the region of 180° C. Thereafter ne error decreases until it reaches zero at about 600° C. At igh temperatures the geometrical error predominates, and ncreases with increasing temperature. The fitted curve, hich requires $K_1 = 1 \cdot 0 \times 10^{-2}$ and $K_2 = 1 \cdot 1 \times 10^7$ deg^3, ives a geometrical error of 10 and a conductive error of 8 t 1000° K, which are of opposite sign as expected. Those xpected on the basis of equations (3), (10) and (15) are 3 nd 10 respectively. The geometrical error is thus rather rger than calculated. In the region of 100° C the observed onductive error is considerably smaller than to be expected rom equation (15*c*) but at this temperature this equation ust be expected to give a considerable over-estimate for the eference thermocouple used herein. More detailed calulations on the basis of equation (15*a*) lead to a value of bout 30 for $T_j = 100°$ C, which is of the right order.

A number of subsidiary observations were made. The eometry of the furnace was "improved" by placing a nickel oil, cleaned on the outside and blackened on the inside, round the central area of the furnace. The error at 300° C as observed to *increase* by 3·0. This is as expected, since this temperature conductive errors predominate but are ormally partly counteracted by the geometrical error. The eduction of the geometrical error by the nickel foil thus increased the total error. The value of the geometrical error at this temperature is given by curve *B* as 5·4° C. A thermocouple of similar design to the reference couple was placed in the specimen position, so that the conduction errors should largely cancel out. It was found that the difference between the two thermocouples at 200° C was reduced to 3, while that at 700–800° C was virtually unaltered. This confirms that conductive errors predominate at low temperatures, and geometrical errors predominate at high temperatures.

The effect of running the two halves of the furnace at different currents was also investigated. Two thermocouples were placed in the furnace, one flush with the furnace wall of one of the furnace halves, and the other flush with the furnace wall of the other half. The furnace was allowed to settle down at 320° C with equal currents in both halves. The currents were then altered to give the same total power, but with 0·525 A running in one half and 0·35 A in the other. Taking the powers as proportional to the square of the currents, equation (6) predicts a difference of 7. The observed change in the difference between the thermocouples was 13° C.

Finally, the effects of imperfect vacuum were checked. At the normal working pressure of about 5 μ, small variations of the pressure had no appreciable effect on the specimen and reference thermocouple temperatures. When, however, the pump was switched off and the pressure allowed to rise to the order of 100 μ, the effects were very noticeable. At all temperatures, it was found that the temperature of both thermocouples rose; the temperature of the reference thermocouple always rose more than that of the specimen thermocouple, which is presumably a consequence of the reference thermocouple being nearer to the furnace walls than the specimen thermocouple, as discussed above.

DISCUSSION

Work on this type of camera has also been reported by Berry, Henry and Raynor.(1) Their results differ from those reported herein for two main reasons: (*a*) highly conducting metal specimens were used which projected into the axial cavities, and (*b*) thermocouples with appreciable conductive errors were attached to the specimen for calibration. As a consequence of (*a*), the portion of the specimen exposed to X-rays was heated appreciably by heat flowing down the length of the specimen from the axial cavities. As explained above, this conduction can not be controlled from one specimen to another and causes large temperature gradients in the specimen; consequently, it must be avoided if precise measurement is to be obtained. These authors also found a temperature maximum in the centre of the specimen which is certainly spurious, since it can easily be shown that its magnitude requires heat to be flowing *away* from the central part of the specimen at many times the rate at which it should be flowing *towards* it to balance radiation losses. This result, together with a difference of about 15 at 500° C between an internal calibration and the thermocouple calibration, is probably due to cause (*b*) above.

In the present work, the calibration was estimated from internal consistency and from the agreement of the observed errors with theoretical expectations, to be within 5° C for the particular use to which it was put—a measurement of the thermal expansion of boron nitride already reported.(3) The principal uncertainties were the possibilities of conduction in the specimen, and of gradients in the furnace gap. This accuracy, which was sufficient in this case, could undoubtedly be improved with more elaborate precautions. However, spherical furnaces such as are used in the newest Unicam camera should prove much more satisfactory, the principal reason being that the axial cavities are removed from the immediate neighbourhood of the specimen, so that steep temperature gradients at or near the base of the specimen are avoided. The geometrical errors will remain approximately as calculated, but the effective radius R remains constant, whereas with the furnace design of Fig. 1, R almost certainly decreased as the temperature was raised, thus accentuating geometrical errors at the high temperatures, an effect which is evident in Fig. 2. The shape of the furnace does not, however, lessen the necessity for careful design of thermocouple, as indeed has recently been reported by Goldschmidt,(4) whose results and recommendations on this point are in substantial agreement with those reported herein.

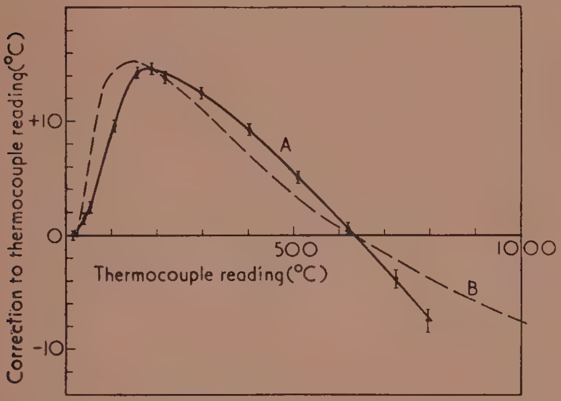


Fig. 2. Calibration of reference thermocouple error

CONCLUSIONS

Thermocouples placed near the ends of the specimen record a temperature different from that of the specimen for two main reasons: the radiation temperature of the furnac is not constant from one place to another; and neither th thermocouple heads nor the specimen are at the radiatio temperature because of conduction down the leads an supports. With an imperfect vacuum, gaseous conductio will also alter the temperatures. In the arrangement used i the present work the two types of error are of opposite sig and result in a relatively complex calibration curve with maximum in the region of 200° C, and a change of sign about 600° C. Design requirements are given to minimiz the errors and to keep them constant from one specimen t another. The three most important are:

(*a*) the head of the thermocouple must be in the ga between the two halves of the furnace;

(*b*) the thermocouple should have a large blackened hea area, with thin leads (approximately 0·005 in. diamete of maximum length (e.g. by coiling) within the furnac gap;

(*c*) the specimen must be effectively insulated from th higher temperatures in the axial cavity.

ACKNOWLEDGEMENTS

It is a pleasure to thank Dr. Thewlis for his help a interest, and Dr. H. J. Goldschmidt for a discussion of t results and encouragement to publish this work.

REFERENCES

(1) Berry, R. L., Henry, W. G., and Raynor, G. V. *J. In Metals*, **78**, p. 643 (1951).

(2) Roberts, J. K. *Heat and Thermodynamics*, p. 2 (Glasgow: Blackie and Son Ltd., 1940).

(3) Pease, R. S. *Acta Cryst.*, **5**, p. 356 (1952).

(4) Goldschmidt, H. J. *Bristol Conference of X-ray Analy Group of The Institute of Physics*, 1955; and *B.S. Report* GRC/G 1109, May 1955.

A simple equipment for solving potential and other field problems

By C. T. Murray, B.Sc., B.E., Electrical Engineering Department, University of Sydney, and
. L. Hollway, D.Sc.Eng., Division of Electrotechnology, Commonwealth Scientific and Industrial Research Organization,
Sydney. Australia

[*Paper first received* 18 *January, and in final form* 17 *March*, 1955]

A method is described for the solution of two-dimensional field problems using, as an electrical analogue, current flow in a sheet of ordinary paper. As the paper resistivity is high, pencil lines are used as electrode boundaries. Details of the circuit and construction of a suitable equipment are given and considerations affecting accuracy are discussed.

or the solution of many static field problems having irregular oundaries, the electrolytic tank has proved to be a very seful analogue computer. (A comprehensive review of nalogue techniques has been given by Liebmann.(1)) One isadvantage of the tank, however, is the length of time eeded to construct and set up the electrode model. Often he initial results show that changes are required in the lectrode form and much of this time is lost. In the present nethod this procedure has been simplified by eliminating the model" stage altogether.(2) Instead, the outlines of the lectrodes, drawn to scale in pencil on a sheet of ordinary aper, are each connected to a source of potential. As the nes are of much lower resistance than the current paths hrough the paper, each remains an equipotential and may epresent the cross-section of a metallic electrode. Measure- ents of the potential pattern established by the conduction urrent are made by touching a probe connected to the grid f an electrometer tube to the surface of the paper.

The method is based on the fact that the resistance of ormal paper is of the order of 1 to 3 × $10^9\ \Omega$ per square. his is high enough to avoid significant potential drops along he pencil lines, for these can readily be kept below $10^6\ \Omega$. On the other hand, the paper resistance is low in comparison ith that of the probe, $10^{14}\ \Omega$, so that the potential distri- ution is not disturbed by measurement.

Experience in the use of this method has shown that it is ossible also to represent regions having different dielectric onstants or different permeabilities by making corresponding hanges in the paper conductivity in those areas. The most onvenient method is to place pieces of paper cut to the orrect shapes, from sheets having the appropriate con- uctivity, in close contact with the back of the drawing.

The operation will now be described in more detail with eference to the simplified circuit shown in Fig. 1.

PRINCIPLE OF OPERATION

A constant potential of 50 V is maintained across the group f potentiometers R_1–R_7 (points A and B in Fig. 1). Six of hese are available to control the potentials of pencil lines epresenting the electrodes on the drawing. The signal, with espect to earth, at the amplifier output is applied to the ivider system as a whole and the input is fed to the amplifier y the electrometer tube probe. As there is a phase reversal n the amplifier and the apparent gain is made infinite by neans of internal positive feedback, whenever the probe is laced at some point on the paper a voltage is developed at he amplifier output which brings that point exactly to earth otential. If the switch S_1 is in the "read potential" position, he potential at that particular point is read directly on neter M.

To trace equipotentials, one point on the contour is first found with S_1 in the "read potential" position. The switch is then moved into the "balance" position and potentiometer R_7 adjusted until the meter reads at the centre of the scale. In this condition the probe movement across the paper appears amplified, up to twenty times, at the pointer, so that the required number of additional points may be readily found. To avoid disturbing the current distribution on the paper it is preferable to make indentations at each position of balance and to draw the continuous lines through after all measurements have been made.

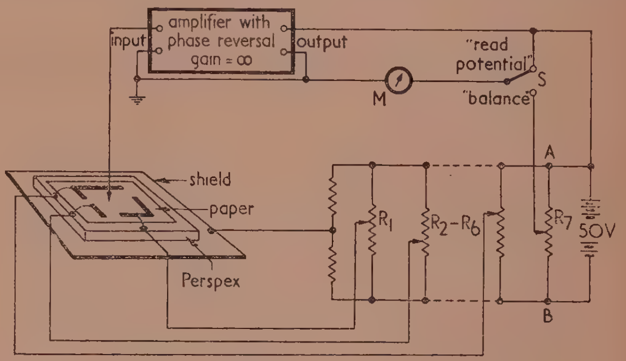


Fig. 1. A simplified circuit of the equipment

At the beginning of a test the probe is brought into contact with each pencil line in turn and the individual potentials are adjusted to represent those of the electrodes to a suitable scale.

CIRCUIT DETAILS

The complete circuit, shown in Fig. 2, is essentially a balanced pentode amplifier with cathode follower output. In order to draw negligible current from the paper an electrometer valve is used as the input stage. It is operated as a cathode follower, the filament being supplied by an isolated and screened transformer winding with selenium rectifier and filter. Anode voltage for this stage is obtained from a potential divider across the main high tension supply. The potentiometer RV_1 allows the electrometer stage as a whole to be adjusted with respect to earth so that its grid, when open-circuited, does not drift away from earth potential.

The amplifying stage consists of two pentodes with common cathode load. One grid is therefore free for adjustment of the d.c. level of the stage and the application of positive feedback from the output. These may be independently adjusted by controls RV_4 and RV_3.

The output cathode follower has as its cathode load the constant current anode circuit of a pentode. This connexion improves the follower characteristics, and also allows the insertion of a fixed resistance in this constant current lead in order to develop the potential source for the pencil electrodes on the paper. This system also allows the amplifier to be coupled to the cathode follower without loss of signal.

For the direct reading and setting of potentials, an 0·5 mA meter is used, with a multiplier, fed directly from the output cathode to earth. Full-scale deflexion is 50 V, the maximum potential available to be applied to the paper. When used as a null indicator, in the "balance" position, the meter is connected through a germanium diode to the cathode of a triode with resistance in both anode and cathode leads. The meter is then protected in the forward direction by the limited current of the valve and in the reverse direction by the diode. The grid of the triode is fed by potentiometer RV_{12} across the constant potential source so that any desired equipotential may be traced, with increased sensitivity, as a null indication. For convenience, the potentiometer RV_{13} allows the meter to be set at centre scale for zero input signal.

To compensate for changes in bias of the constant current valve, due to variation in mains voltage, a small current from the unregulated high voltage supply is passed through its cathode resistor. Similarly, the anode load of the amplifier returned to a slider on the h.t. series dropping resistor whic may be adjusted to correct for changes in d.c. level due t variations in filament voltage of the electrometer valv These two connexions make the apparatus almost complete independent of mains variations.

In the interests of long-term stability it is desirable to u high stability components throughout.

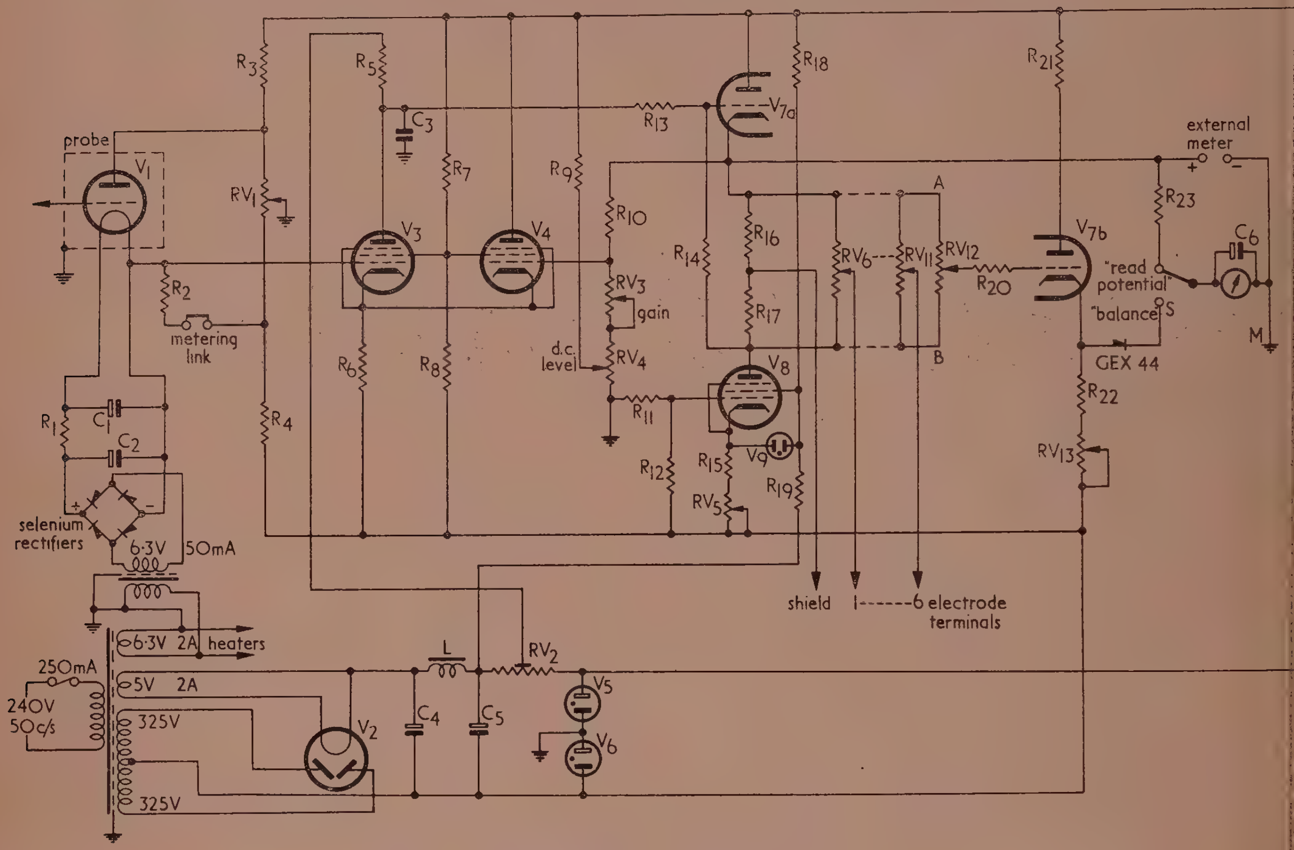

probe
V1
RV1
R2
metering link
R1
C1
C2
selenium rectifiers
6·3V
50mA
250mA
240V
50c/s
6·3V 2A heaters
5V 2A
325V
325V
V2
R3
R4
R5
C3
R6
R7
R8
R9
V3
V4
R10
RV3
gain
d.c. level
RV4
R11
R12
R13
R14
V7a
R18
R16
R17
V8
R15
V9
RV5
R19
RV6
RV11
RV12
R20
A
B
shield
1------6 electrode terminals
L
RV2
C4
C5
V5
V6
R21
V7b
external meter
+
−
R23
C6
"read potential"
"balance"
S
M
GEX 44
R22
RV13

Fig. 2. Complete circuit of the equipotential tracer

R_1 = 500 Ω
R_2 = 100 kΩ
R_3, R_4 = 150 kΩ, 1 W
R_5 = 470 kΩ
R_6 = 200 kΩ, 1 W
R_7 = 100 kΩ
R_8 = 250 kΩ
R_9 = 200 kΩ
R_{10} = 1 MΩ
R_{11} = 150 kΩ

R_{12} = 56 kΩ
R_{13} = 2 MΩ
R_{14} = 1·5 MΩ
R_{15} = 10 kΩ
R_{16}, R_{17} = 25 kΩ
R_{18} = 250 kΩ, 1 W
R_{19} = 1 MΩ
R_{20} = 250 kΩ
R_{21}, R_{22}, R_{23} = 100 kΩ

RV_1 = 10 kΩ
RV_2 = 5 kΩ, 10 W
RV_3, RV_4, RV_5 = 5 kΩ
RV_6–RV_{13} = 250 kΩ

C_1 = 100 μF, 40 V
C_2 = 500 μF, 12 V
C_3 = 0·01 μF
C_4, C_5 = 16 μF, 600 V
C_6 = 25 μF

V_1 = ME1401
V_2 = 5Y3
V_3, V_4 = 6AU6
V_5, V_6 = VR150/30
$V_{7a,b}$ = 12AT7
V_8 = 6AM6
V_9 = NE2

L = 15 H, 60 mA
M = 0–0·5 mA

A general view of the complete equipment is shown Fig. 3. The plotting table consists of a suitably support sheet of ¼ in. thick Perspex, the reverse side of which copper-sprayed. This metallic coating is connected to t electrode potential supply and acts both as a shield a capacitive negative feedback. This feedback is importa when there is a large area of paper enclosed between t pencil electrodes for in this condition, if the shield we earthed, oscillation could be caused by the distribut resistance and capacitance of the paper sheet.

INITIAL ADJUSTMENT

In normal use no adjustments are necessary. When t tracer is first put into operation the circuit is brought optimum performance in the following way:

(*a*) With the probe connected to one of the electrode rminals the potential between A and B is adjusted to 50 V y means of the constant current control RV_5.

(*b*) To ensure that the grid of V_1 floats at earth potential hen open-circuited, a 0–100 microammeter is inserted in ace of the metering link in the cathode circuit. The otentiometer RV_1 is then adjusted so that the reading of the eter remains constant whether the probe input is earthed floating.

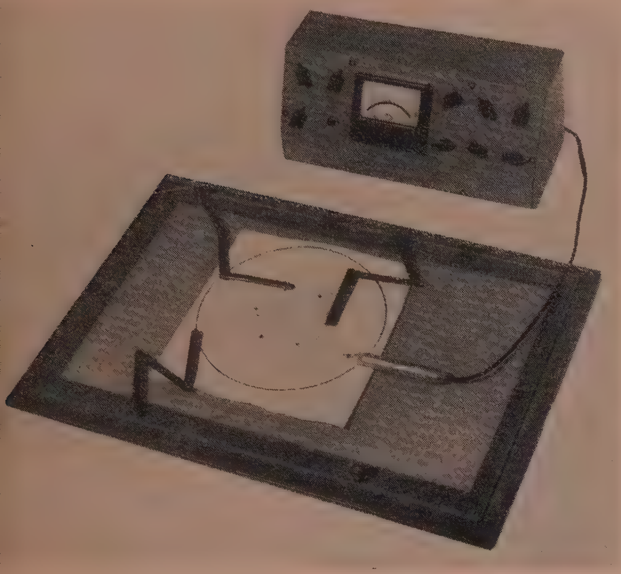


Fig. 3. The construction of the tracer. Folding contact arms make connexion with the pencil lines

(*c*) The error voltage at the electrometer grid is removed the d.c. level and gain controls. The probe is connected one of the electrode terminals and the error voltage of is point with respect to earth is read by means of a illivoltmeter. With the electrode control at end A, so at the potential meter reads zero, the error voltage is set zero by means of potentiometer RV_4. With the electrode ntrol at B (50 V) the error voltage is brought to zero by otentiometer RV_3.

(*d*) The probe is connected to the contact arm of RV_{12} and V_{13} adjusted so that the output meter reads "centre zero" the "balance" position.

PERFORMANCE

When the circuit conditions have been adjusted as escribed, the error signal appearing at the probe is negligible ess than 0·05%) and the only remaining errors are those sociated with the meter and the possibly non-uniform conductivity of the paper. In testing the inherent accuracy of the apparatus the meter was replaced by a precision potentiometer and a number of examples using parallel and concentric electrode systems were plotted. Using good quality papers, such as "bank" or drawing paper, it was found that the displacement of any equipotential from its true position rarely exceeded 2% of the electrode separation. This error was found to be due to the anisotropy of the machine-rolled papers then being used which showed different properties along and across the direction of rolling. The use of a hand-made paper (Whatman's "hot-pressed") reduced the error to less than 1%. Such a paper is not rolled in the process of manufacture and is termed "square" in paper technology. [An investigation of the errors introduced by machine-made papers has also been made by Dahlen.(3)]

The tracer also lends itself to problems involving discontinuities in conductivity (or dielectric constant, etc.). Fig. 4 shows the field pattern for a region having a dielectric constant of two. The error at the points shown is within ±2%. While larger errors may be found in more complex examples, the accuracy should be sufficient for many design problems.

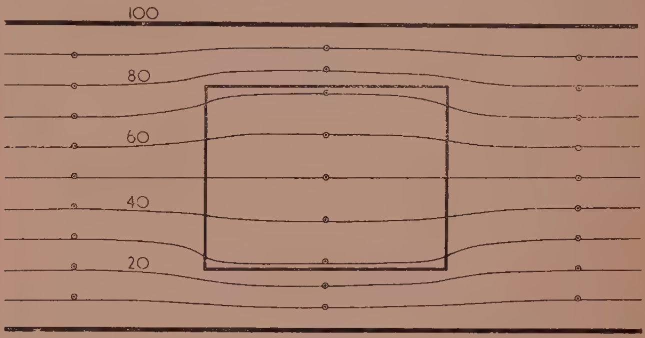


Fig. 4. The field pattern between parallel plates including a region having a dielectric constant of 2. The circles mark calculated positions of the equipotentials (scale arbitrary).

ACKNOWLEDGEMENTS

The authors wish to thank Professor D. M. Myers and Mr. R. E. Aitchison of the Electrical Engineering Department, University of Sydney, for their interest and encouragement.

REFERENCES

(1) Liebmann, G. *Brit. J. Appl. Phys.*, **4**, p. 193 (1953).

(2) Murray, C. T., and Hollway, D. L. *J. Appl. Phys.*, **24**, p. 110 (1953).

(3) Dahlen, E. B. *Rev. Sci. Instrum.*, **25**, p. 951 (1954).

Laboratory and workshop notes

The measurement of small changes in dielectric constant by means of a cavity wavemeter

By E. S. Hotston, B.Sc., A.Inst.P., and J. E. Houldin, Ph.D., F.Inst.P., College of Technology, Birmingham

[*Note first received* 29 *April, and in final form* 8 *June*, 1955]

The use of a cylindrical H_{01n} cavity resonator for the measurement of dielectric constant and power factor of disk-shaped dielectrics is well known.(1–3) The resonator is a vertical cylinder with the upper end closed and a movable piston forms the lower plane face. Suitable coupling holes to a power source and a resonance detector are placed in the walls of the cavity. The usual method of operation is an adaptation of the resonance method used at lower frequencies with lumped circuits.(4) The position of the piston required for resonance with the resonator empty is found, the dielectric is inserted into the cavity and the change in length Δl of the resonator is observed (Fig. 1). The dielectric constant of the disk can be calculated from the diameter of the resonator, the thickness of the disk, Δl and λ_g. (λ_g is the wavelength of the standing electromagnetic wave in the air-filled part of the resonator and is obtained from successive resonant settings of the piston.)

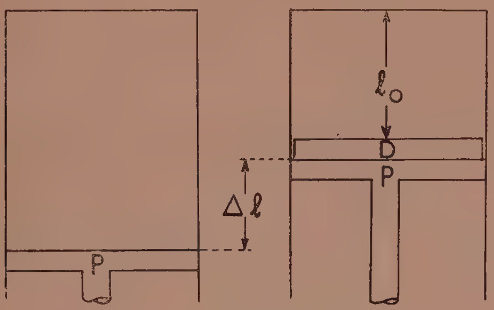


Fig. 1. Section through resonator
P, piston; *D*, dielectric disk.

There are several disadvantages in this method. The resonator must be constructed so that it can be re-assembled to a high degree of repeatability when the dielectric is inserted. Also the oscillator must have high frequency stability of the order of 1 or 2 parts in 10000 over the period of a measurement, which might in some cases be several hours. If it is desired to measure the temperature coefficient of dielectric constant, the resonator and thermal insulators should have negligible coefficients of expansion.

These difficulties can be overcome if the resonator is designed so that it is possible to measure directly l_0 the length of the air-filled part of the resonator (see Fig. 1). The dielectric constant is then determined from l_0, the diameter of the resonator and the thickness of the specimen. Δl is not required. As the determination of dielectric constant no longer depends on the difference of two resonant settings of the plunger, the requirements for frequency stability of the oscillator and low expansion of the resonator are not so severe.

The method of exciting a resonator as described by Bleaney and others(5) allows the distance l_0 to be measured by moving the piston up to the top face of the resonator. Slip gaug are used in conjunction with the micrometer head.(6) O form of resonator is illustrated in Fig. 2. In this design t piston does not rotate. The dielectric is inserted by removi the top cap.

The piston makes a good sliding fit with the base plate the resonator, and may be centred by means of the screws The lower end of the piston is held in contact with the s

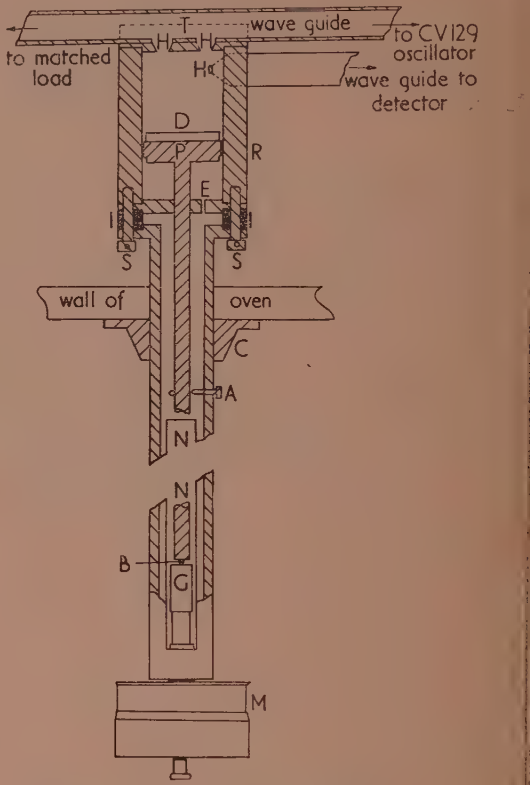


Fig. 2. Resonator used for measurements
A, screws; *B*, ball bearing; *C*, clamp; *D*, dielectric; *E*, bas plate; *G*, slip gauge; *H*, coupling holes; *I*, thermal insulator *M*, drum micrometer with ratchet; *N*, slit for *G*; *P*, piston *R*, resonator; *S*, screws; *T*, top cap.

gauge *G* by gravity. The slip gauge rests on top of micrometer hammer. A set of counter weights (not sho are used to take most of the weight of the piston off thread of the micrometer screw.

Experiments with an empty resonator show that the act physical length at resonance differs from an integral num of half wavelengths by a small amount termed the e correction. This correction arises from the field deformat due to the coupling holes. It is assumed that it is independ of the presence of the dielectric in the resonator, and correction is added on to the actual value of l_0 for the purp of computing dielectric constant. It is found experiment for the resonator shown that the end correction is independ of frequency over the 4% frequency range investigated. I also independent of the temperature from 20 to 150° C.

One serious source of error in measurements of this t is the presence of dust inside the resonator. The measur technique described here enables checks of consistency t made readily before and after a series of measurements.

At frequencies of about 9600 Mc/s it has been found possible repeat measurements of dielectric constants of glass disks ·08 in. thick to within 1 part in 750, at room temperature. is thus possible to measure small variations of dielectric onstant such as may arise from adsorbed layers, or tempera-re variations. The use of a thin sample of dielectric enables e Q-factor of the resonator to be kept high and only a nall amount of coupling between resonator, and the scillator and detector need be used.

The authors are indebted to the Board of Admiralty for nancial assistance and permission to publish this note. hey would also like to express their gratitude to Mr. L. rierley and the late Mr. A. Darby who constructed the quipment.

REFERENCES

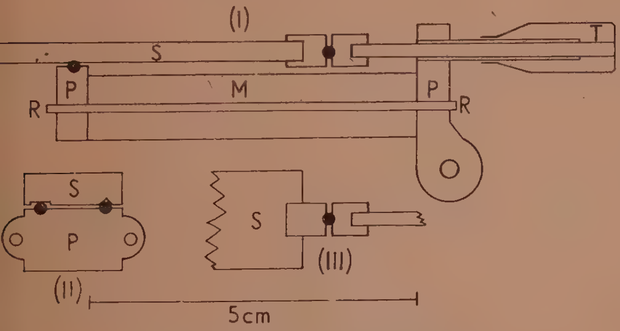
) Horner, Taylor, Dunsmuir, Lamb and Jackson. *J. Instn Elect. Engrs*, **93** (III), p. 53 (1946).
) Barlow and Cullen. *Microwave Measurements*, Chapter IX (London: Constable and Co. Ltd., 1950).
) Jackson, Powles and Penrose. *Trans Faraday Soc.*, **42**, pp. 91–114 (1946).
) Hartshorn. *Precision Measurements of Dielectric Constant, N.P.L. Symposium on Electrical Measurements.* Paper 1 (1954) (London: H.M. Stationery Office, 1955).
) Bleaney, Loubser and Penrose. *Proc. Phys. Soc.* [*London*], **59**, pp. 185–194 (1947).
) Essen. *Proc. Roy. Soc. A*, **204**, pp. 260–277 (1950–51).

Magnetic coupling for a kinematic slide

By B. G. Cragg, M.A., Ph.D., Department of Anatomy, University College, London

[*Note first received* 24 *March, and in final form* 27 *April,* 1955]

he difficulty of attaching retaining springs to a fully kinematic ide can be avoided by making the slide and the micrometer art of a magnetic circuit. As shown in the figure, the soft on pole-pieces are bolted with brass rods to the ends of a ar magnet which forms the body of the instrument. The icrometer nut is held in the proximal pole-piece which also rms a supporting lug for the whole assembly. The soft on slide completes the magnetic circuit between the distal pole-piece and the screw of the micrometer, making contact with each through steel balls. Two balls are seated in the distal pole-piece, one making contact with the faces of a longitudinal vee channel in the slide, and the other bearing on a flat face on the underside of the slide. A third steel ball separates the micrometer screw from the slide and is partially seated in each. Thus the magnetic force acts across the balls at each of the contacts and springs are unnecessary. With an "Eclipse" bar magnet of the dimensions shown in the figure the bearings will support a weight of 200 g attached to the slide. The instrument is satisfactory as a manipulator of microelectrodes used in electrical recordings from the central nervous system.



Construction of kinematic slide

(i) Elevation of whole assembly
(ii) Cross-section of distal bearing
(iii) Plan of proximal coupling

M, magnet; *P*, pole-piece; *S*, slider; *R*, brass rod; *T*, thimble of micrometer.

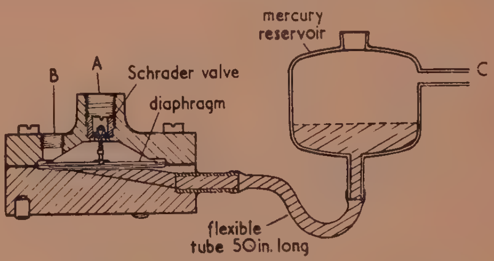
I wish to thank Mr. H. J. Coates and Mr. C. E. Lyons for constructing the instrument.

A valve for regulating differential pressures at small gas flows

By D. Anson, Ph.D., Dominion Physical Laboratory, Lower Hutt, New Zealand

[*Note first received* 23 *February, and in final form* 7 *April,* 1955]

The accompanying sketch shows the design of a simple valve, suitable for laboratory use, for regulating differential pressures. It uses as its reference the pressure due to a mercury column. The valve gives close regulation for flows up to one or two l./min of air, depending on the pressure. Variations in supply pressure are reduced by a factor of approximately 1/300, so that with primary supply regulation to ± 1 lb/in^2. a final regulation to better than 1/100 in. of mercury is readily obtained. The normal operating range is between 0 lb/in.^{2} and 25 lb/in.^{2} differential pressure, above which the length of the mercury column becomes excessive. The differential can be maintained between any two pressures in the safe working range, including vacua.



Differential pressure regulating valve

The action of the valve will be clear from the sketch. For normal use, the lower pressure of the differential system is connected to *C*, the higher pressure to *B* and the high pressure supply to *A*. Any increase in the differential gas pressure results in the diaphragm being depressed against the mercury column so that the Schrader valve closes the supply. To supply gas at a steady gauge pressure, the mercury reservoir is left open to the atmosphere at *C*. Vacua can be controlled by connecting *B* to the vacuum system and leaving both *A* and *C* open to atmosphere, the mercury reservoir being lowered below the level of the diaphragm in this case. In these two instances control is, of course, with respect to atmospheric pressure. In all applications the mercury column must be heavily damped, and a screw clamp on the flexible tube has been found effective for this purpose.

The body of the valve is of mild steel. The 0·010 in. thick polythene diaphragm used serves also as a gasket. The diaphragm is reinforced by a light steel plate, bonded to it as a means of location, and carrying a flat smooth anvil at its centre to ensure even operation of the control. This anvil operates a Schrader valve (of the type used in motor tyres) modified by cutting back the stem on the inlet side, and refitting the spring on the delivery side. The valve seat is of stainless steel, and incorporates a slack guide for the valve stem; it was modelled on the original one, with, of course, a different external form. The entire valve assembly is retained by a screw against a soft washer, and can readily be removed for adjustment or cleaning. As the diaphragm has a very restricted movement (about ±1/32 in.) the length of the valve stem must be carefully adjusted.

The mercury reservoir is of glass, and is provided with a tight stopper. Both the mercury reservoir and the diaphragm are 2 in. in diameter. A very small increase in the mercury head operating over this diameter provides ample force to overcome that due to the supply pressure acting on the valve, and it is this which is the principal factor in determining the closeness of control. Adjustment, made by varying the level of the mercury reservoir, is facilitated by incorporating a simple fine adjustment mechanism, such as a screw.

This note is published by permission of the Secretary, Department of Scientific and Industrial Research.

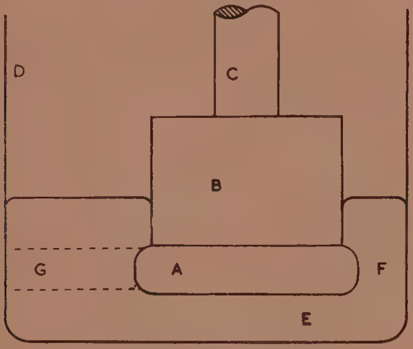
Protective cover for a stop watch

By P. E. Watson, M.A., A.Inst.P., Laporte Titanium Ltd., Luton, Beds

A thick polyvinyl chloride cover for a laboratory stop watch will normally prevent damage should the watch be dropped three or four feet on to a concrete floor. Such a cover has the additional advantages of making the watch less liable to be mislaid and of acting as a bench stand.

The method of construction of a polyvinyl chloride cover is illustrated in the figure. A piece of close-grained wood or plastic is first turned to the approximate shape and size of the watch *A*. A cylinder of the same material is turned to the diameter of the watch glass, about 1 in. long, *B*. These two are fixed to the end of any suitable bar material *C*. The bar is supported vertically as shown in an 8 cm diameter beaker *D*, so that the clearance at *E* and *F* is about ⅜ in. Plastic paste is poured into the beaker to cover *A* to a depth of about ⅜ in. Bubbles are allowed to rise to the surface and the whole assembly is placed in an oven at 150° C for about one and a half hours. When cooled, the solid mass is removed from the mould and a ½ in. hole, *G*, is bored radially
inwards with a cork borer lubricated with glycerine. This
to accommodate the winding button of the watch. A shar
lubricated knife is used to cut away the polyvinyl chlori
to provide a deep peripheral groove to accommodate t
operator's finger. A flat may be cut opposite the hole *G*
act as a base for standing the watch upright. The button
the watch is provided with shallow saw cut across the en
For ease of inserting the watch in the cover it should
lightly smeared with Vaseline and snapped into place. Th
watch is wound with a small screwdriver in the shallow sa
cut which prevents excessive force being applied.

The plastic paste may be coloured if required by t
addition of a few per cent of pigment ground in tri-cres
phosphate before moulding.



Arrangement of mould

Silver–palladium thermocouples

By C. R. Barber, B.Sc., F.Inst.P., and L. H. Pemberton,
National Physical Laboratory, Teddington, Middlesex

[*Note received* 24 *March*, 1955]

Silver–palladium thermocouples have been in use for sever
years at the National Physical Laboratory as secondar
standards for the calibration of base-metal thermocouples
the range of temperature from 200 to 600° C. They hav
given a high degree of constancy and have greatly facilitate
the calibration work since they have not required freque
re-standardization.

The advantages of using pure metals for the thermocoup
elements instead of alloys are that, provided the wires can
protected from contamination, the risk of changes of calibr
tion is greatly reduced, and the wire is likely to be mo
homogeneous. Apart from contamination from extraneo
sources there are two other possible sources of parasitic electr
motive force, namely, the diffusion of the metal of one ar
into that of the other and oxidation. Oxidation of palladiu
occurs at comparatively low temperatures and is revealed
a bluish-black discoloration on the wire. That no serio
error would arise from these causes was established
investigating the effect of changes in immersion on therm
couples heated for 70 h at 600° C; no parasitic electromoti
force could be detected.

Thermocouples of silver and palladium to be used
standards in a stirred liquid bath* are prepared in t
following way. Wires 0·5 mm in diameter and 1·5 m lo
are annealed electrically, the palladium wire at a temperatu
of about 1400° C and the silver at about 700° C. They a
mounted in a flat twin-bore silica tube 45 cm long, 3 m
wide and 2 mm thick, and the silver wire is fused on to t
palladium wire to form the "hot" junction. The twin-bo
sheath is then placed in a closed-ended silica sheath protect
by a stainless steel sheath, the outer diameter of which
6 mm. The rest of the wire is insulated with Systoflex sleevi
and protected from sharp bends by flexible steel tubing rigid
attached to the stainless steel tube at one end and to the gla
reference-junction protection tube at the other.

Three thermocouples were constructed in this manner a
used exclusively in a stirred salt bath up to a temperature
630° C. After three years (1946–48) they showed changes
electromotive force at the boiling point of sulphur (444·600°
equivalent to −0·05, +0·05 and +0·07° C. After a furth
two years (1948–50) the electromotive forces at the sar
temperature showed further changes equivalent to +0·
+0·46 and +0·14° C. These standards were subsequen

---

* Grace, A., and Hall, J. A. *J. Sci. Instrum.*, **20**, p. 60 (194

scarded owing to repeated fracture of the wires and replaced three others which have shown changes of electromotive rce at 444·600° C of the equivalent of +0·21, +0·18 and 0·11° C after three years' use. The number of tests in hich these thermocouples have been used has risen from out thirty a year in 1947 to sixty a year in 1954.

A typical calibration of the silver–palladium thermocouple set out in the table. It is far from linear, giving about μV/° C at 200° C and 34 μV/° C at 600° C. Although e components of the thermocouple are pure metals, the rity is not sufficiently reproducible from batch to batch of e wire to permit a standard calibration, and it is necessary calibrate each thermocouple. For example, at the sulphur int two samples of palladium wire gave electromotive rces against a silver wire which differed by 108 μV, and o samples of silver wire against a palladium wire gave ectromotive forces which differed by 5 μV. The palladium res had values of 1·3750 and 1·3780 for the R_{100}/R_0 ratio d the silver wires, 1·4085 and 1·4108.

ypical e.m.f.-temperature calibration of a silver–palladium thermocouple (Reference-junction temperature 0° *C*)

Temperature °C	*e.m.f. μV*
200	2 880
250	3 817
300	4 840
350	5 956
400	7 171
450	8 489
500	9 915
550	11 456
600	13 114

It must be emphasized that the silver–palladium thermouple is only suitable for laboratory use and even then must handled carefully, since the wires are not mechanically ong and bending must be kept to a minimum. However, e experience described above shows that they can be nployed successfully for high-accuracy temperature measureent of liquid baths in the temperature range for 200 to 0° C and it is concluded that an accuracy of ±0·1° C can achieved and maintained for considerable periods.

The work described above has been carried out as part of e research programme of the National Physical Laboratory d the note is published by permission of the Director of e Laboratory.

Marker fringes

By W. Thomson, B.Sc., G.I.Mech.E., Ministry of Supply,
Directorate of Weapons Research (Defence), Tolworth,
Surrey

[*Note received* 14 *April*, 1955]

recent investigation entailed evaluations of the flatness of ge numbers of glass plates up to 9 × 9 in. in size and ving irregularities of as much as 30 or 40 μ in some instances. r reasons of expediency it was decided to employ an erference-fringe method, although this was recognized as mewhat over-sensitive for easy application to such a oblem.

A full-size photograph of the Fizeau interference pattern each plate against an optical flat was obtained, and the parture from flatness was originally measured by counting nges (Fig. 1). Since with the usual mercury green line each fringe-interval represented roughly 0·25 μ, this was a lengthy and laborious process.

This difficulty has been overcome by using in the interferometer a Kodak No. 44 ("minus red") filter, in conjunction with a Hewittic mercury lamp, type 547C (by Hackbridge and Hewittic Electric Co., Ltd.), run at low pressure. The filter suppresses the strong yellow lines, and the resultant separate fringe-patterns, formed by the green (5461 Å) and violet (4358 Å) lines, combine to produce the well-known coincidences and discordances on the interferogram (Fig. 2). With the wavelengths mentioned above, coincidences recur at intervals of four green fringes, or very approximately at

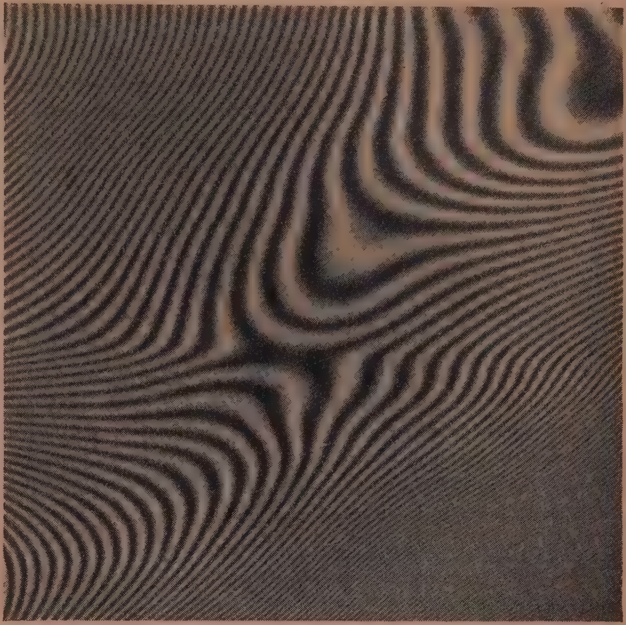


Fig. 1. Ordinary fringe-pattern

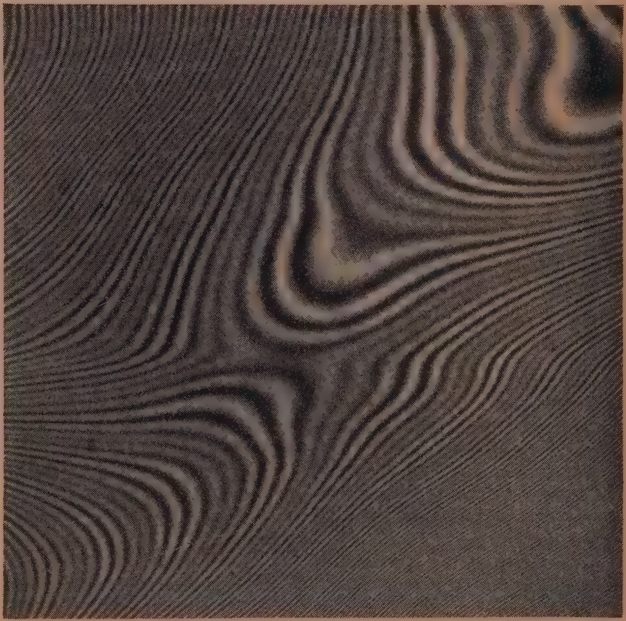


Fig. 2. Pattern with "marker fringes"

every micron change in the air-film thickness. The maxima of these act as "marker fringes," and greatly facilitate the counting operation, so that the total out-of-flatness of a plate can immediately be read off in microns from the photograph.

Marker fringes at coarser intervals (about every 5 μ) could be provided by suppressing the violet radiation, and using the combination of the green and yellow lines.

Acknowledgement is made to the Chief Scientist, Ministry of Supply, for permission to publish this note.

Non-sticking float-valve for vacuum systems

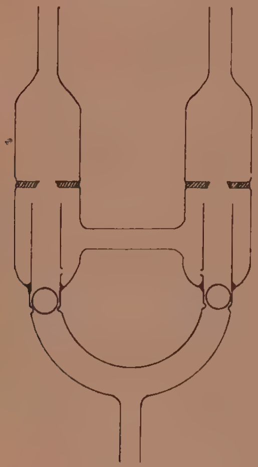
By H. H. Neville, M.A., Ph.D., Chemistry Department, University of Aberdeen

[*Note received* 4 *April*, 1955]

Greaseless valves employing a float ground into a glass seat are notoriously prone to stick. Mercury cut-offs using sintered-glass disks are free from this trouble, but severely restrict the flow of gas at low pressure. The valve here described combines the best features of both types in a compact unit which is easily made.

The sintered disks, of porosity 4, are drilled with a central hole of about half the diameter of the stainless steel ball floats. The holes are then bored out to about three-quarters of the ball diameter. These operations are done on a small lathe, running at slow speed, using ordinary high-speed tools. Three balls are each soft-soldered to a piece of brass tube, and used for grinding the spherical seats in the edges of the holes, using Carborundum F, 3F, and finally Diamantine. This can be done by hand in a few minutes. Eight pairs of seats have been ground with one set of balls without causing excessive wear on the third ball.

After grinding, the seat is inverted, a new ball placed on it with some mercury, and the space beneath evacuated to test for leakage round the seat. When the grinding is satisfactory, two disks are assembled as shown in the figure, the balls being inserted before completing the U-limb at the foot. The tubes in which the balls slide are provided with small holes to permit the mercury to flow away. The U-limb is connected with a mercury reservoir in the usual way.



When the valve is opened by lowering the mercury level, the ball on the side connected to vacuum sticks at first. When the pressure is nearly equalized by passage of gas through the sintered disk, this ball drops, and opens an unrestricted path for the gas. The weight of the ball, small area of contact with its seat, and the angle of cont of about 45° ensure that the ball invariably drops after n equalization of pressure.

The dimensions are not critical. The diameter of hole should be about three-quarters that of the ball, a half that of the whole disk. Valves have been made w holes of 10 mm and 5 mm diameter for use with bor hydrides. These valves were made at Queen Mary Coll (University of London) with the assistance of Mr. W. D and Mr. Callen.

Preparation of tungsten apparatus for high temperature resea

By J. D. Mackenzie, Ph.D., J. A. Kitchener, Ph.D., and J. O'M. Bockris, D.Sc.,* Department of Chemistry, Imperial College, London

[*Note received* 19 *April*, 1955]

The advantages of tungsten apparatus (m.p. 3380° C) for at high temperatures are somewhat offset by the extre brittleness and hardness which render cold-working diffic However, a technique developed to "form" tungsten she at red heat has made possible the preparation of shall containers and tungsten-lined crucibles.

A circular tungsten sheet, 0·005 in. thick, is secured betw two $\frac{3}{16}$ in. thick steel plates of a die,(1) the small cylindri steel plunger placed in position, and the whole clamped heat-insulating Sindanyo asbestos caps on a vice. T tungsten is then raised to red heat with a blow torch a slowly forged into shape. Shallow tungsten dishes, $1\frac{1}{2}$ diameter and $\frac{3}{16}$ in. deep, have been successfully prepar Oxidation was not excessive and the coating of oxide easily removed by chemical or mechanical means.

Attempts to prepare tungsten crucibles by the weld technique described for molybdenum(1) were unsuccessful the welded seams usually failed after the sheets had b formed at high temperatures.(2) Tungsten-lined crucib $1\frac{1}{2}$ in. diameter and $3\frac{1}{2}$ in. high, with an external grap casing, were made by first forming a hollow cylinder out a 0·005 in. sheet with the mild steel roller shown in Fig

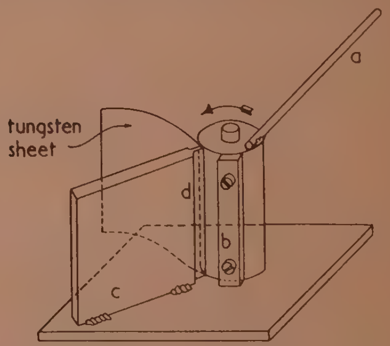


Fig. 1. Tool for bending tungsten sheet at red heat

The sheet was clamped at *b* between the rigid steel pla and the roller, which was fixed on a refractory brick platf and heated red-hot along the edge *d*. The sheet was rolled by moving the handle *a* in the direction indicated. shallow dish described above was inverted and placed in a graphite crucible of slightly greater internal diameter.

---

* Now at University of the Witwatersrand, Johannes South Africa.

llow cylinder was then forced into the graphite crucible, hich had a shallow internal groove to accommodate the erlapping ends, and pressed hard on to the bottom. After ating to 1800° C, solid-phase welding of the crucible ttom to the cylinder, and of the overlapping ends occurred, sulting in a leak-proof crucible.

To determine the suitability of tungsten as a containing aterial at various temperatures and ambient atmospheres, e simple apparatus shown in Fig. 2 was found to be satis- ctory. Small "boats" (1 in. × $\frac{1}{8}$ in.) were made out of 005 in. tungsten sheets, filled with the test material, and amped between two thick brass electrodes ($\frac{3}{8}$ in. diameter) closed in an inverted 1 litre round flask by a rubber stopper. fter the flask had been filled with the desired atmosphere, rrent was switched on and the tungsten strip became fectively the filament of a lamp. Temperature was con- olled by adjusting the current through a Variac transformer d its measurement made by sighting a portable optical rometer on the tungsten filament. The life of the filament us indicated the rate and extent of any attack.

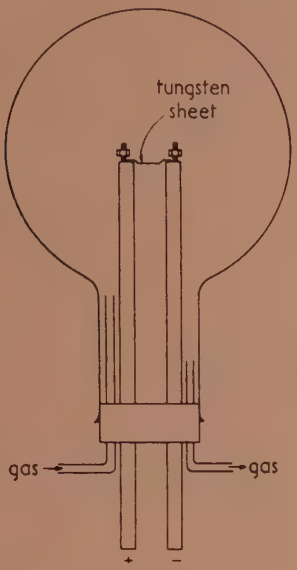


Fig. 2. Method of testing resistance of tungsten to hemical attack by melts

These techniques have been successfully employed in an vestigation of the viscosity of liquid silica up to 2060° C.(2,3)

Thanks are due to the British Iron and Steel Research ssociation for financial support.

REFERENCES

) TOMLINSON, BOCKRIS, LOWE and MELLORS. *J. Sci. Instrum.*, **31**, p. 107 (1954).
) MACKENZIE. Thesis, University of London, 1954.
) BOCKRIS, MACKENZIE and KITCHENER. *Trans Faraday Soc.* To be published.

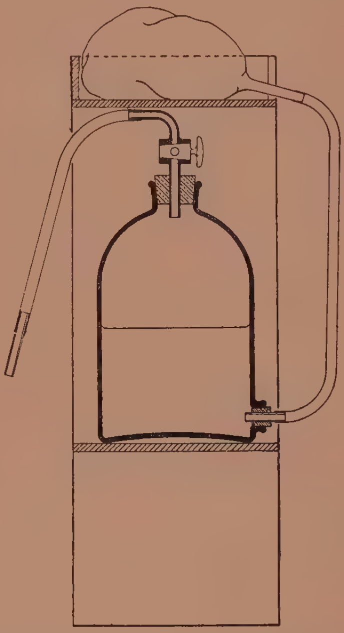
A simple and robust aspirator for flue-gas sampling

By C. H. BUCK, B.Sc., A.M.Inst.Gas.E., A.Inst.P., Radiation Ltd., Aston, Birmingham 6

[*Note received* 1 *June*, 1955]

mples of flue gases are frequently required and when it is sired to measure both carbon dioxide and carbon monoxide, . by means of an infra-red gas analyser, the sample volume eds to be approximately two litres. A common method collecting these samples is to use a Berzelius gas-holder consisting of an aspirator bottle fitted with ground-in glass stop cocks at top and bottom and with a large capacity funnel with a stop cock ground in at the top neck. In addition to this it is necessary to use another receptacle, for example an empty Winchester vessel, to receive the confining liquid as the gas sample is drawn into the aspirator.

A more robust and inexpensive device can be constructed from a standard aspirator bottle having a bottom opening without tap and a glass tap fitted at the top. The bottle is fitted into the centre section of a wooden stand as shown in the figure. The bottom opening is connected by means of a short length of flexible tube to a football bladder. In order to collect a sample, the aspirator is filled with confining liquid and is then connected to the sampling tube. The football bladder is placed in the space underneath the aspirator bottle and the tap is opened, allowing the sample to be drawn into the bottle while the bladder inflates with liquid. In order to discharge the sample into the gas analysis apparatus the bladder is placed on the top shelf of the apparatus, as shown in the figure, and the tap is opened.



Aspirator for flue-gas sampling

This note is published with the permission of the Directors of Radiation Ltd.

Electrode for measuring the conductivities of solutions at low pressures

By R. C. BRAUN, B.Sc., A.R.I.C., Hendon Technical College, London

[*Note received* 13 *April*, 1955]

In the course of some investigations on the rate of solution of salts at low pressures, it was found necessary to design an electrode which would measure changing conductivities at low pressures of the order of 10^{-1} mm of mercury.

The electrode described was designed to be suitable for flask mounting and was found satisfactory for the measurement of varying and steady conductivities at low pressures. Although the electrode was used mainly at pressures of about 10^{-1} mm of mercury and above, it would serve equally well at pressures below this.

The electrode consists of an outer glass jacket made from glass tubing of 15 mm diameter (Figs. 1 and 2). This tubing is joined to a B. 19 standard ground glass joint. A short piece of slightly tapered glass tubing is sealed to the upper end of the ground glass joint. A cork grooved to take the two main wire leads is fitted into the top of this tube. A rubber cap with two openings for the wire leads fits snugly over the top of the tube. This assists in keeping the cork in position and prevents the leads from being displaced.

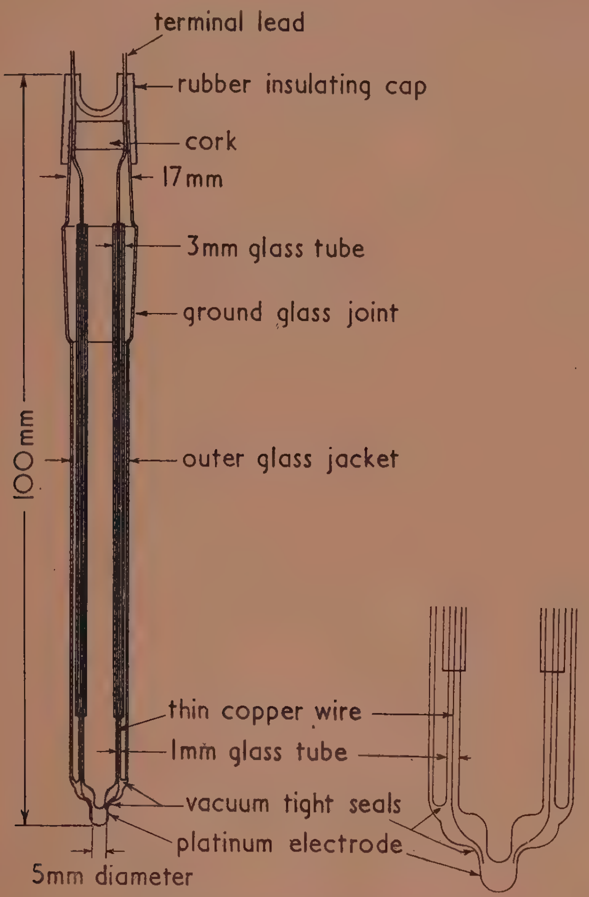


Fig. 1. Electrode showing detailed construction

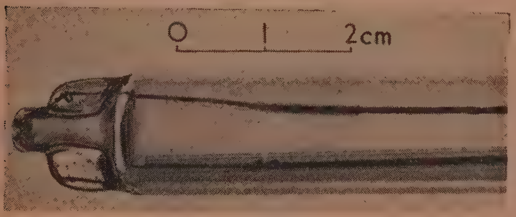


Fig. 2. Lower part of electrode showing metal-glass seals

The wire leads pass down inside the glass jacket and are protected from each other and also kept rigidly in position, by encasing them in glass tubing 3 mm in diameter. At a distance between 20 and 30 mm above the lower end of the electrode the main wire leads are joined to some thin copper wire, the latter being also encased in glass tubing of 1 mm diameter; this fits just inside the lower end of the 3 mm tubing. The copper wires are sealed into the glass by means of a metal–glass seal, which must be vacuum tight. Tl are then joined on the outside of the tube to the platin electrodes. The latter are made from platinum foil a measure 3 × 2 mm. They are separated by a short piece solid glass forming a blob of about 5 mm diameter at end of the main glass tube. The inside of the foil is sea into the glass so that the platinum electrodes cannot su displacement. The overall length of the electrode is 100 r to fit a 1 litre round-bottomed flask. This can be varied suit any size of vessel by altering the length of the outer gl jacket.

The cell constant of this electrode was determined in t usual manner and found to be 2·39. The electrode was th mounted in a 1 litre round-bottomed flask fitted with standard B. 19 socket and also a socket for a vacuum-tig stirrer, which incorporated a device for evacuating the fla The flask was then evacuated to the desired pressure.

This work was carried out in the laboratories of Hend Technical College, with the aid of a grant from the resear fund of the Chemical Society. The author is grateful Prof. J. O'M. Bockris for advice and encouragement.

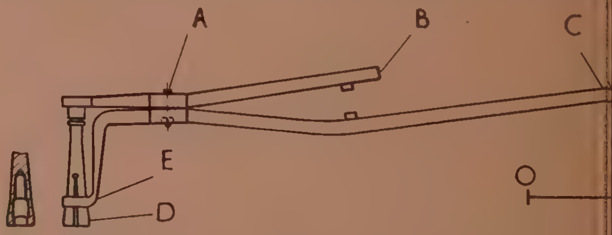
Tool for removing the objective aperture from a type E.M electron microscope

By J. Betts and P. B. Hosier, The British Aluminium Co. Ltd., Chalfont Park, Gerrards Cross, Bucks.

[*Note received* 8 *June*, 1955]

In the type E.M.3 electron microscope,* by Metropolita Vickers Electrical Co. Ltd., fitted with an adjustable object aperture, the aperture disk is carried in a standard specim cap which slides over the slotted end of a carrier tube. T tube assembly has to be inserted and removed through t door of the specimen chamber. Ordinary forceps have be found awkward to use, there being a tendency for the specim cap to be pulled off the carrier tube so that the aperture d falls down inside the objective lens. The special tool design to overcome this difficulty is simple in construction and, the same time, easy to manipulate in the confined work space available.

The general construction of the mild steel tool is shown the figure. The joint at *A* is loose, and when the handles and *C* are squeezed together against the stops the collet is closed by the taper ring *E* (the total movement of taper ring necessary to achieve this is $\frac{1}{16}$ in.). The collet ja can be released by opening the handles. The inside of collet jaws has been enlarged slightly (see inset) to clear specimen cap, so the jaws grip on the carrier tube alo just below the cap, and the whole assembly can be remo or inserted easily.



Sectional view of tool for removing aperture

---

* Haine, M. E., Page, R. S., and Garfitt, R. G. *J. Appl. Ph* **21**, p. 173 (1950).

IEW BOOKS PUBLISHED BY THE INSTITUTE OF PHYSICS

Monographs for Students Series

umidity. By H. L. Penman, Ph.D., F.Inst.P. Pp. 71.

rors of observation and their treatment. By J. Topping, Ph.D., F.Inst.P. Pp. 119. Price 5*s*. each.

ie Monographs for Students Series is intended for general ading by students such as those in the first two years of a gree course in either science or engineering or for those ading for Higher National Certificates.

Dr. Penman's monograph summarizes concisely the funda- entals of the subject and outlines many methods of measur- g and controlling humidity.

In his preface Dr. Topping says, "Every teacher of experi- ental physics knows how 'results' given to three or four cimal places are often in error in the first place; students ffer from 'delusions of accuracy.' At a higher level too, ore experienced workers sometimes claim a degree of curacy which cannot be justified. Perhaps a consideration the topics discussed in this monograph will stimulate students an attitude to experimental results at once more odest and more profound."

Both monographs contain references and bibliographies for ose readers who wish to pursue the subjects further.

Physics in Industry Series

Physics of fibres. By H. J. Woods, M.A., F.Inst.P. Pp. 100. Price 30*s*.

This latest addition to the Physics in Industry Series of monographs has been written as an introduction to the subject of fibres for scientists commencing research and development work in this field. The author has also had in mind those scientists whose interests are in other fields, but who may wish to learn something about the ways in which physics has helped in advancing our knowledge of fibres. Throughout this book the emphasis is on the natural rather than the man-made fibres; the author considers that anyone who knows something about cellulose and keratin should find little difficulty with other fibres. The headings of the chapters are: Fibre structure in general; The dimensions, form, and general physical properties of fibres; X-ray diffraction investigations; Optical properties; Elastic properties; Electron microscopy of fibres.

A bibliography and a fairly full list of references have been provided for those who wish to pursue the subject further.

OTHER NEW BOOKS

uclear radiation detectors. By J. Sharpe. (London: Methuen and Co. Ltd., 1955.) Pp. i + 179. Price 11*s*. 6*d*.

onographs in this series are intended for readers ranging om Honours students to "those who are no longer in ntact with active scientific work," but this one will not ppeal to the superannuated physicist. It is really a book r those who are concerned with designing, using or choosing unters of nuclear radiations and who want the quantitative iysical data that determine the performance of various pes of detector in various circumstances. The principles of tection are, of course, discussed, but the book is most otable for its numerous tables, graphs and references. It is ncerned specifically with detectors, not with amplifiers or cording apparatus. Occasional short cuts in physics or iraseology give transient feelings of insecurity; but Mr. iarpe knows where he is going and carries the reader th him.

P. B. Moon

itten's watch and clock maker's handbook, dictionary and guide. 15th ed. Revised by J. W. Player, F.B.H.I. (London: E. and F. N. Spon Ltd., 1955.) Pp. vii + 598. Price 63*s*.

ie reappearance of this much-quoted work will afford nsiderable satisfaction to all those interested in the very oad field associated with horology. The book has been tensively revised and topics of current interest either added considerably expanded.

This book is written as an encyclopaedic dictionary, as in evious editions, making for ease of reference and reading. ch listed topic is followed by its French, German and anish equivalent and the treatment is a happy combination the historical, practical and theoretical. An appendix gives variety of properties of materials, mathematical tables and ar trains, a table of local times and a glossary of French, German and Spanish terms. A reasonably full index coupled with the format of the book makes reference very easy.

A number of excellent horological textbooks, encyclopaedias and dictionaries are now readily available and the introduction of a new book or the reissue of an old one will be received into a fairly critical atmosphere. Nevertheless, the reviewer feels that the issue of this edition will be welcomed by all, from the practical man and student to the amateur and collector. The standard of production is high and the layout is pleasing. The volume is copiously illustrated and in content is comprehensive. The reviser is to be congratulated on carrying out so effectively what was obviously a very exacting task and deserves the thanks of all prospective readers. The price is not small, but the reviewer feels that this is a book which those interested in the subject will wish to acquire and will find good value.

J. F. W. Bishop

Graphical design of optical systems. By L. E. W. van Albada. (London: Sir Isaac Pitman and Sons Ltd., 1955.) Pp. v + 153. Price 21*s*.

Quite a number of people seem to be interested in the reasons for the rather complex lenses made for various purposes and quite a number of people prefer geometrical descriptions to algebraic or numerical ones. Those who belong simultaneously to both classes would possibly be interested in this book. It describes an ingenious method of ray-tracing graphically. Naturally it cannot be as accurate as the standard arithmetic methods of calculation and the author does in fact give a chapter on the numerical tracing of rays. Perhaps in the problem of designing condenser lenses and the like a graphical ray trace may be more useful than a numerical ray trace, but no professional lens designer would use such methods; as the author states in the preface, the book is intended primarily for amateur optical workers.

J. L. Houghton

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep him informed of their new or impro products. The Institute of Physics assumes no responsibility for the statements given below: information for these has b taken from literature supplied.

Three-metre grating direct-reading spectrometer. Hilger and Watts Ltd., Hilger Division, 98 St. Pancras Way, London, N.W.1.

The Polychromator is one of a number of direct-reading spectroscopic and spectrophotometric instruments made by this firm. Its operator inserts a metallic, liquid or powder specimen in a suitable discharge stand and presses a button. Within 4 minutes the instrument has determined up to thirty constituents of the specimen and has printed the results on a strip of paper. The saving of time, in comparison with methods involving photographic processing and microphotometry leads to considerable economies and greater certainty in the production of alloys. The name of the instrument is derived from its optical system, this being, in effect, a number of monochromators in parallel.

Light from a vertical arc or spark is focused on a horizontal entrance slit, so that not only can a chosen layer of the discharge be used, but any wandering of the source takes place along the length of the slit. The light is dispersed by a 3-metre concave grating and falls on an assembly of exit slits, accurately positioned on the focal surface to isolate suitable spectral lines of thirty selected elements. A small mirror system behind each slit focuses the light on the cathode of a photomultiplier (see figure).

Photomultiplier assembly showing arrangement of the slits and mirrors

The grating is ruled by Siegbahn and is mounted to compensate thermal effects not entirely eliminated by the insulation of the cabinet. If the grating expands, its dispersion decreases and it automatically moves, in compensation, further from the focal surface, if it contracts, its dispersion increases and it moves nearer to the focal surface. A constant distance between two rays of given wavelengths is thus maintained at the slits.

The initial setting of the slits is facilitated by an arrangement allowing the exposure of a length of film immediately in front of the focal surface. In general, the setting is intended to be permanent, since the choice of thirty elements is adequate for the analysis of a considerable range of alloys.

An allowance of fifty locations for the photomultipli
gives flexibility in arranging them relative to the slits. Pho
multipliers with quartz windows give the instrument
wavelength range of from 1940 to 6000 Å; they are of a t
developed by Electric and Musical Industries' Resea
Laboratories and have very high sensitivity, low dark curr
and exceptional stability. The outputs of the photomultipli
are integrated simultaneously during the exposure, and s
sequently measured consecutively, in a separate electro
console. The integration is effected by a series of plastic-f
capacitors, one for each photomultiplier channel; th
dielectric absorption is very low and their leakage is negligi
They are associated with relays discharging them at
beginning of a run, and connecting them to their respect
photomultipliers during the exposure and in sequence to
measuring circuit at the end of the exposure.

The measuring system is claimed to be unique am
spectroscopic instruments. It uses a quartz crystal oscilla
to time the interval required to charge a comparison capacit
from a highly stabilized d.c. source, to a potential equal
that of the integrating capacitor being measured. The circ
is so arranged that the rate of change of potential across
comparison capacitor is constant and hence the "scale"
the instrument is very closely linear. The frequency of
crystal is 10 000 c/s and its oscillations are counted in u
up to 9999. Counting ceases as soon as equality of poten
is attained. The count is displayed on four dekatron tu
and is subsequently printed, together with a number ident
ing the element concerned. The error due to drift is less t
a count of one unit, and the standard deviation of a read
is about one part in 8000. The manufacturers state t
results of comparable accuracy, if displayed by a pen recor
would require a chart 200 in. wide.

The comparison with each integrating capacitor is c
pleted, as is evident, in less than 1 s; this and the subsequ
printing of the result together take 6 s. Immediately a
the printing of one result, a uniselector brings the
capacitor into the measuring circuit. The channels to
measured in any particular analysis are selected by depress
switches on the front of the electronic console, and o
channels are by-passed by the uniselector without loss of ti
The input resistance of the measuring circuit is sufficie
high, and its capacitance sufficiently low, to allow
capacitor to be measured repeatedly without apprecia
discharging it. Such repetition is achieved by pressin
button on the console. Two clock-dials on the con
enable the operator to set the instrument for suitable
sparking and exposure periods. The exposure period ma
either of definite duration or of the time required for
internal-standard channel to reach a predetermined poten

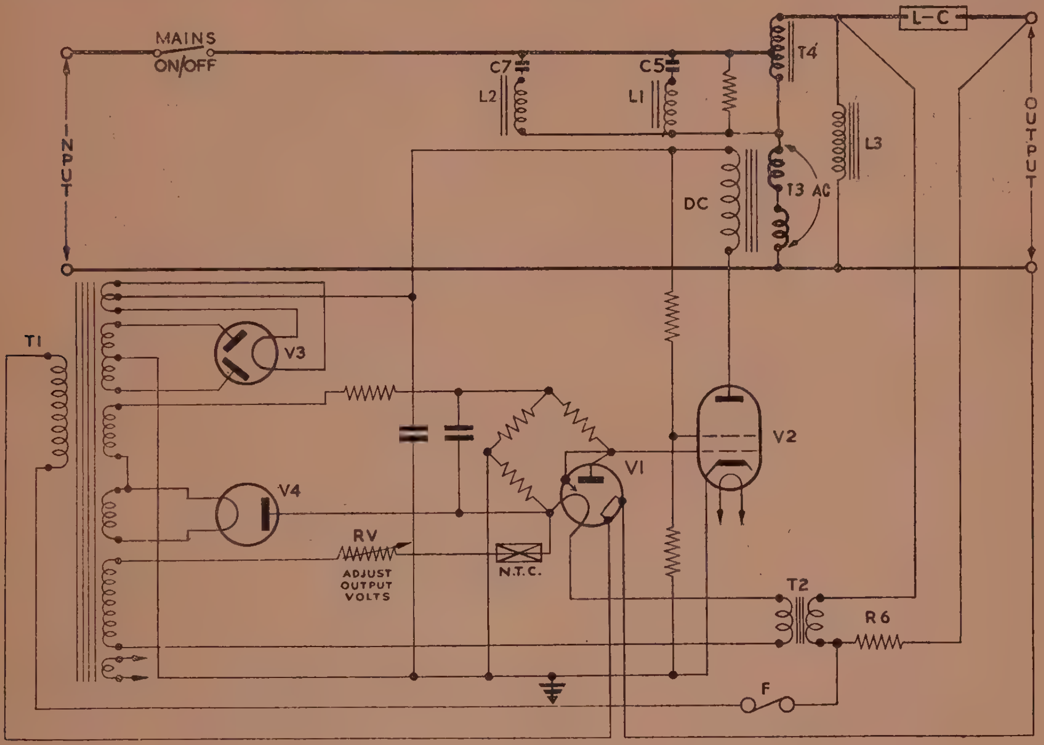
The sequence of operations performed by the instrum
from the moment the starting button is pressed is as follo
a sequence timer is switched on and a fatiguing la
(beneficial to the photomultipliers during non-wor
periods) is switched off. The sequence timer, during its
revolution, discharges the integrating capacitors for 5 s
then switches on the source unit and the pre-spark cl
As soon as the pre-spark clock reaches zero, the expo
clock starts and the capacitors are connected to their ph
multipliers. The exposure clock stops at the end of

posure, the source unit is switched off, and the capacitors
e isolated. The sequence timer now makes a complete
volution, occupying 6 s, during which the measuring circuit
ro is automatically corrected. The uniselector connects the
easuring circuit to the first position for which the key has
en depressed. During the next revolution of the timer, the
unter is reset to zero, the zero-control is switched off for
s, and the count corresponding to the capacitor potential is
ade and recorded. The uniselector repeats the cycle until
the required channels have been measured. With a pre-
ark period of P seconds, an exposure time of E seconds,
d n channels to be measured, the total time consumed by
analysis is $P + E + 6(n + 1)$ seconds, which in general
less than 4 minutes for all thirty channels.

The manufacturers claim that the instrument has a very
gh degree of dependability and is designed to make servicing
d maintenance as simple as possible. Monitoring facilities
e included to allow checking from the control panel.

ternating voltage regulator. J. Langham Thompson Ltd.,
Bushey Heath, Herts.

e LT–1000–2S voltage regulator is designed to produce
alternating output stabilized to within 0·1% for changes
input voltage from 190 to 260 V and for changes of load
m no-load to full-load. The circuit is shown in the figure.
e regulator depends for its operation on the control
rcised by a saturable-core reactor T_3 in series with an
o-transformer T_4 in the mains power circuit (shown in
diagram by heavy lines). A change in the direct current
wing in the control winding causes a variation of impedance
the reactor and consequently affects the output voltage of
auto-transformer. The voltage reference stage consists
a resistance bridge in which one element takes the form of
pecial diode V_1 operating in a temperature-limited con-
on, so that its impedance depends on the filament current.
The filament is supplied from the output of the regulator *via* transformers T_2 and T_1 so that changes in output affect the impedance of the diode and the balance of the bridge. The output from the bridge is applied to the grid of the power tetrode V_2, the anode current of which passes through the control winding of the reactor T_3. The secondary of the transformer T_2 is connected in anti-phase with that of T_1 and the ratio of the two determines the sense of the control. The voltage applied to T_2 is obtained from the drop across R_6 which is in series with T_1, so that the ratio of the voltages applied to these two transformers can be adjusted by varying R_6. Compensation for change in load, including the resistive effect of the output leads, is made by adjusting the load compensating resistance LC. This consists of a helix of connecting wire inserted in the output circuit and connected so that the voltage developed across it by the output current acts in series with that developed across R_6 and applied to the transformer T_2. Output *voltage* is stabilized against change of input voltage or load by connecting T_1 across the output terminals as shown in the figure. Output *current* can be stabilized against change of input voltage or output load by connecting T_1 in series with the output. Output *power* can be stabilized against change of input voltage or load impedance by having two primary windings on T_1 and connecting one in series with the load and the other across the output terminals.



Circuit of alternating voltage stabilizer

Radiation pyrometer. Cambridge Instrument Co. Ltd.,
13 Grosvenor Place, London, S.W.1.

The Cambridge quick-response Féry telescope has been developed from the standard model. The front window of special glass is attached by magnets and may be changed in a few seconds, while the mechanical layout allows any adjustment to the mirror or the radiation receiver to be made with minimum interruption of readings. The shortest normal working distance is 3 ft and the size of the hot area must not be less than about 1·7 in. for every 3 ft distance. The makers state that the normal rate of response of the instrument is such that 99% of a radiation input corresponding to a full-scale reading will be measured in 4·6 s and 99·9% in 6·9 s. For exceptional applications at moderate temperatures a specially fast receiver can be provided to give 99% of full-scale response in 1·2 s and 99·9% in 1·8 s.

Incremental inductance bridge. General Electric Co. Ltd., Magnet House, Kingsway, London, W.C.2.

This unit is a reversed Owen bridge which has provision for passing d.c. through the inductor under test. It enables the incremental inductance and the associated dynamic series resistance of an inductor to be determined under known conditions of a.c. and d.c. excitation. The instrument incorporates a 45–1500 c/s variable oscillator, but can employ frequencies from 20 c/s to 5 kc/s with an external source of 7 kΩ output impedance. It covers an inductance range from 0·1 mH to 1000 H in six ranges, the accuracy of direct measurement being about 1%. The resistance range covered by the bridge extends from 0·01 Ω to 1 MΩ and the inductance and series resistance can be read off the instrument directly, independent of frequency and with a common range multiplier. Very high and very low *Q* inductors can be measured and, since the inductance dial is calibrated from zero, the bridge can be used for measuring the a.c. resistance of non-linear devices such as lamps, thermistors and rectifiers with a d.c. bias. The bridge consists of three self-contained units which can be arranged for either bench use or standard rack mounting. One unit consists of a d.c. supply unit continuously variable currents from 0–300 mA and is p vided with a 0–350 voltmeter and a current meter. ripple is 12 mV at 100 c/s on open circuit. The second u is the bridge in which six inductance and resistance ranges selected by a range switch. The third unit incorporates a.c. supply for the bridge, a cathode-ray tube balance indica and a valve voltmeter for reading the alternating volt across the test terminals of the bridge. The oscillator is resistance-capacity type, continuously variable from 45 1500 c/s, the output being 1·3 W into an impedance 7000 Ω.

Electronic recorder. Fielden Electronics Ltd., Paston Ro Wythenshawe, Manchester 22.

The recording pen of the Fielden Servograph (Mark electronic recorder is operated by a servo-motori mechanism and is controlled by a moving-coil. The nor indicating pointer is replaced by a light metal vane wh acts as one plate of a variable condenser. Another sim vane, turned by the servo-mechanism, moves in the sa arc as the meter-operated vane, the distance between the being kept constant by an electronic capacity relay wh controls the servo-motor. It is only necessary to prov enough energy in the input circuit to deflect the indicat instrument movement; the servo-mechanism then locates pen arm.

The manufacturers claim that this principle enables accu records of small current variations down to parts of a mic ampere to be obtained.

Manufacturers' publications

Copies of the publications mentioned in this section are normally obtainable gratis from the manufacturer named.

Magnetic ferrites. Mullard Ltd., Century House, Shaftesbury Avenue, London, W.C.2. A reference book of 130 pages entitled *Mullard Ferroxcube* is available at a nominal price of 7*s.* 6*d.* It deals comprehensively with the properties and applications of Ferroxcube. Exhaustive data are given on all Mullard Ferroxcube components, including pot-cores, transformer-cores for communications and television, aerial rods and special components, with descriptions of the design procedures necessary to make use of them.

Fluorocarbons. The Edison Swan Electric Co. Ltd., 155 Charing Cross Road, London, W.C.2. An illustrated booklet lists the properties of polytetrafluoroethylene (PTFE) and polymonochlorotrifluoroethylene (PCTFE). It also compares the properties of PTFE with polythene, polystyrene and nylon and suggests various applications.

Thermoplastic material. Hercules Powder Co. Ltd., 140 Park Lane, London, W.1. A new booklet describes the characteristics of Akulon rod material which is a nylon suitable for injection and extrusion moulding.

Vacuum equipment. Edwards High Vacuum Ltd., Manor Royal, Crawley, Sussex. Leaflet D. 153/1 describes the Philani vacuum gauge which is a combination of the Philips and Pirani type gauges. Leaflets E. 108/5 and E. 101/5 describe types 6E and 12E vacuum coating units respectively; both units are small and suitable for experimental work. Leaflet E. 144/2 gives details of evaporation filaments, baskets and boats, while leaflet H. 106/2 provides information on suitable evaporation materials.

Variac autotransformers. The Zenith Electric Co. L Villiers Road, London, N.W.2. A nine-page catalogue g full specifications of the latest additions to the range Variac autotransformers.

Humidity instruments. Cambridge Instrument Co. L 13 Grosvenor Place, London, S.W.1. Folder 70 B g details of various instruments which either indicate, rec or control humidity.

Stereoscopic and dissecting microscopes. W. R. Prior Co. Ltd., Northgate End, Bishop's Stortford, Herts. catalogue describes a range of stereoscopic and dissec microscopes together with various accessories.

Megger insulation testers. Evershed and Vignoles L Acton Lane Works, London W.4. Guidance in selecting most suitable Megger insulation tester is given in an illustra leaflet. The information takes the form of charts wh include details of scale ranges, catalogue numbers, prices, Full size reproductions of typical instrument scales printed in the leaflet which is the forerunner of a m comprehensive guide book at present being prepared.

Sine generator. Dalmotor Company, 1331 Clay St Santa Clara, California, U.S.A. Leaflet Form GPM–3–1 describes a small generator which produces simultaneous two-phase sine wave and two indicating pips per revolut The leaflet includes a list of mechanical and electrical sp fications and performance curves relating output voltag volts to load resistance in ohms for operation at both 2 (1200 rev/min) and 35 c/s (2100 rev/min).

Notes and comments

ections to The Institute of Physics

The following elections have been made by the Board of e Institute of Physics:

Fellows: R. G. Allen, C. J. Brown, A. E. Calnan, R. F. rr, A. S. Gladwin, W. J. Harris, A. W. Norris, R. F. Y. ndall, J. K. Robertson, G. L. Rogers, N. Thompson.

Associates: R. E. Bentley, H. A. Bernstein, P. J. Black, W. Fearn, J. H. Haywood, D. Houseman, J. R. Kirkman, E. Liley, A. P. Lloyd, C. Mack, G. G. Miller, A. F. Moore, D. Moore, W. G. Pryce, J. H. Rayner, E. J. Robbins, M. Roberts, M. Roy, E. Sheldon, R. F. Youell.

Thirty-eight Graduates, forty-seven Students and two bscribers were also elected.

tes for prospective authors

Authors preparing contributions for submission to this *urnal* are invited to make use of the guidance available a 32-page booklet entitled *Notes on the preparation of ntributions to the Institute's Journals and other publications.* is intended to assist less-experienced authors and to serve a reference booklet for all who wish to contribute to the stitute's publications. It gives hints on the preparation of ripts and diagrams, on the lay-out of mathematics for the inter, the correction of proofs and so on. In addition to a ort bibliography of reference books and works on technical iting, there are lists of the spellings, symbols and abbrevia- ns used by the Institute. These conform with British andard 1991, Part 1: 1954. *Letter symbols, signs and breviations, Part* 1, *General*, which authors of mathe- itical papers are also advised to consult.

Copies of the booklet may be obtained from The Institute Physics for 2*s*. 6*d*. (including postage).

fe transport of scientific instruments

For purposes of comparison it is often necessary for boratories in different countries to exchange scientific struments. To enable these transfers to be made safely and ickly the United Nations Educational, Scientific and ltural Organisation has introduced a scheme in which stoms officials are present when the instruments are packed d unpacked. An internationally recognized label is ached to such packages which are then exempt from rmal customs procedure.

The governments of those laboratories using the scheme ovide the Director-General of Unesco, Paris, with a list of laboratories and details of the methods, including customs ocedure, by which they propose to operate the scheme. present, twenty-two governments have named more than 0 laboratories as participants in the scheme.

ossary of acoustical terms

The British Standards Institution has issued a revision of glossary of acoustical terms which was first issued in 36. There are many changes in the contents and arrange- ent of the new edition, and about eighty new terms have en added (an increase of about 40%). The section on cording and reproduction has been enlarged and new ctions on ultrasonics and underwater sound have been luded.

The first edition contained a number of musical terms ich have now been deleted. The following headings are ose used in the new edition: fundamentals; propagation; aring; transmission systems; ultrasonics; underwater sound; instruments; recording and reproduction; music; architectural acoustics.

Copies of the standard, price 6*s*., may be obtained from the British Standards Institution, Sales Branch, 2 Park street, London, W.1.

Exhibition of dividing machines

Until the middle of the eighteenth century measuring scales used in instruments were divided by hand or by the use of a dividing plate. The first successful dividing engine was built in 1775 by Jesse Ramsden and divided circular scales mechanically. Improvements since then have yielded increased accuracy and dividing machines are now used to engrave the graduations on linear and circular measuring scales. To illustrate the evolution of the dividing machine eight circular dividing machines are being exhibited for a few months at The Science Museum. The earliest is dated 1778 and the latest 1955; two of them will be shown in operation.

Journal of Electronics

We have received the first issue of a journal "devoted to electron sciences," entitled *Journal of Electronics* and associated with *The Philosophical Magazine*. The Editor is Dr. J. Thomson and the Consultant Editor is Professor N. F. Mott. The following comment is taken from the editorial: "The field of this journal is not easy to define. In a very real sense we shall be concerned with phenomena directly attributable to the electron, but since most of the properties of matter fall into this category, it is necessary to make some distinction between the field of the journal and the field of the rest of natural science. In the brochure distributed by the publishers the field was defined as 'electron science . . . interpreted to mean the description of the behaviour of electrons in the free state or in states where their binding energy is low,' which we had hoped describes what the editors had in mind."

In this first issue of 102 pages measuring 10 × 7 in. there are nine papers with the following titles:

On the initial space charge distribution in a cylindrical magnetron diode; The space charge distribution in the pre-oscillation magnetron; Theory of the preoscillating magnetron I; Factors in the design of power amplifiers for ultra high frequencies; Some experiments on a cylindrical electron beam constrained by a magnetic field; On the solution of an equation of electron optics; Note on moving striations; A review of the structure and some magnetic properties of ferrites; Recent research with an experimental mass spectrometer.

The format and typography of this journal are similar to those of its parent journal (*The Philosophical Magazine*); although adequate, they are perhaps a little dull and unimaginative for so promising an offspring. The journal is to be issued every other month at £1 per issue and the subscription price for the volume of six issues is £5 10*s*. 0*d*. The publishers are Taylor and Francis, Ltd., Red Lion Court, Fleet Street, London, E.C.4.

The protection of workers against ionising radiations

We have received a copy of a very readable and informative sixty-six-page report presented by the International Labour Office to the Geneva Conference on the Peaceful Uses of Atomic Energy entitled *The protection of workers against ionising radiations*. It was prepared for the ILO by Mr. K. L. Goodall, H.M. Chemical Inspector of Factories, and covers the following subjects: Part I, the interests of the ILO in radiological protection; Part II, the history of radiation injuries, the nature and properties of the various ionising radiations and the injurious effects to which they can each give rise; Part III, standards of exposure; Part IV, the manifold uses of ionising radiations in medicine, agriculture and industry; Part V, the general and special precautions appropriate for radiation workers in atomic energy plants, factories, hospitals and research laboratories; Part VI, problems arising in uranium mining and processing; Part VII, the packing, labelling and transport of radioactive materials. A number of appendices include the ILO Model Radiation Code, a summary of the current ICRP recommendations on permissible doses and examples of suitable medical record forms for the clinical and haematological examination of radiation workers.

Copies of the report may be obtained from the International Labour Office in Geneva or from the United Kingdom Office at 38–39 Parliament Street, London, S.W.1, price 3*s.* 0*d.* (50 cents). It is also available in French and Spanish.

British Standards Institution

The annual report of the British Standards Institution for the year ended 31 March, 1955, has just been issued and again records continued growth in its activities. Nearly 900 000 copies of British Standards were sold during the year and 4000 Committee Meetings were held! There are 8300 subscribing members of the institution drawn from commercial firms, trade associations and professional bodies. Two interesting developments are the growth in the number of codes of practice which have been issued and in the amount of international and oversea work in which the institution participates.

The many subjects covered by new and prospective standards include the following: laboratory furniture, components for telecommunications, glossaries of specialized terms in various fields, graphical symbols for instruments, graduation of instrument scales, barometer conventions, letter symbols and abbreviations, conversion factors and tables, statistical methods.

High-speed photography

A third international congress on high-speed photography is to be held in London from 10 to 15 September, 1956, at Government Offices, Horse Guards Avenue, London, under the sponsorship of the Department of Scientific and Industrial Research. An international exhibition of high-speed photographic equipment will also be mounted in the same building. It is the intention of the exhibition committee to bring together research and commercial exhibits which will be representative of the latest work in the following and other fields: flash light sources; inertialess shutters; mechanical–optical drum cameras; image sampling techniques; schlieren, interferometric stereoscopic colour photomicrography.

The exhibition committee invites exhibits and reserves the right to accept those exhibits most appropriate to the congress. Further details may be obtained from Department of Scienti and Industrial Research, Charles House, 5–11 Regent Stre London, S.W.1.

Frontiers in physical optics

A symposium on the frontiers of physical optics will held in Cambridge, Massachusetts, from 28 March to 3 Ap 1956. The sponsors are: International Commission Optics, International Union of Pure and Applied Physi National Academy of Sciences, National Research Coun of the U.S.A., National Science Foundation of the U.S. American Academy of Arts and Sciences, American Opti Society.

Four days will be allocated to the symposium in which main subjects for discussion will be new phase contrast a interference microscopic and measuring devices; thin fil and filters; meteorological optics; nuclear optics. One d will be allocated to the 1956 Meeting of the Internatio Commission for Optics and one day will be set aside organized visits to university and industrial laboratories the Boston–Cambridge area. Invitations will be issued the U.S.A. National Committee to experts in vari countries to present main papers on each of above-not subjects and perhaps prepared discussion also. It is, howev the intention to leave ample time for free discussion.

Further particulars can be obtained from Dr. S. S. Balla Visibility Laboratory, Scripps Institution of Oceanograp University of California, San Diego 52, California, U.S.A.

Erratum

In the paper "A capacitance-resistance hygrometer," C. L. Cutting, A. C. Jason and J. L. Wood, published in November issue of this *Journal*, line 21 (right-hand colu of p. 425 *should read:* The thicknesses of the films t formed for unit current density (1 mA/cm^2) are 0·62 ± 0 microns.

British Journal of Applied Physics

Contents of the December issue

SPECIAL ARTICLE

Industrial applications of ultrasonics. By E. G. Richardson.

ORIGINAL CONTRIBUTIONS

The thermal conductivity of liquid and gaseous oxygen. By H. Ziebland J. T. A. Burton.

Propagation of transient fields from dipoles near the ground. By H. Poritsk

Technical properties of iron powder magnets. By E. H. Carman.

A simple adaptation of the carbon replica technique for the examinatio selected areas in the electron microscope. By D. E. Bradley.

The influence of cathode standing waves on valve stability. By W. W. H. Cl

The deposition of thin films of gold on cylindrical specimens by sputtering. F. R. Lipsett.

The γ-ray spectrum of fission products from slow neutron irradiation of ura 235. By D. H. Peirson.

NOTES AND NEWS

Correspondence

Conditions for aperiodicity in linear systems. From R. H. Macmillan; A Fuller.

The flexural vibrations of an end-loaded vertical strip. From J. P. Ellingto

The orientation of fibres in an electric field. From S. Whitehead; P. La J. O. Isard.

New books

Notes and comments

THIS *JOURNAL* is produced monthly by The Institute of Physics, with the co-operation of the National Physical Laboratory. It deals with the principles construction and use of scientific instruments. All rights reserved. Responsibility for the statements contained herein attaches only to the writers.

EDITORIAL MATTER. Communications concerning editorial matter should be addressed to the Editor, The Institute of Physics, 47 Belgrave Square London, S.W.1. (*Telephone:* Sloane 9806.) Prospective authors are invited to prepare their scripts in accordance with the *Notes on the preparation o contributions.* (Price 2*s.* 6*d.* including postage.)

REPRODUCTION. The Institute of Physics is a signatory to The Royal Society's Fair Copying Declaration. Details may be obtained upon applicatio from The Royal Society, London, W.1.

ADVERTISEMENTS. Communications concerning advertisements should be addressed to the agents, Messrs. Walter Judd Ltd., 47 Gresham Street, London E.C.2. (*Telephone:* Monarch 7644.)

CLAIMS FOR MISSING JOURNALS. Claims from regular subscribers to this *Journal* for missing numbers will only be considered if received within 6 days of the date of mailing plus normal outward time of transit and time for lodging the claim. Losses attributable to failure to notify a change of addres or to similar omissions will not be considered.

SUBSCRIPTION RATES. A new volume commences each January. The charge is £4 per volume ($11.50 U.S.A.), including index (post paid) payable i advance. Single parts, so far as available, may be purchased at 8*s.* each ($1.15 U.S.A.), post paid, cash with order. Orders should be sent to The Institute o Physics, 47 Belgrave Square, London, S.W.1, or to any bookseller.